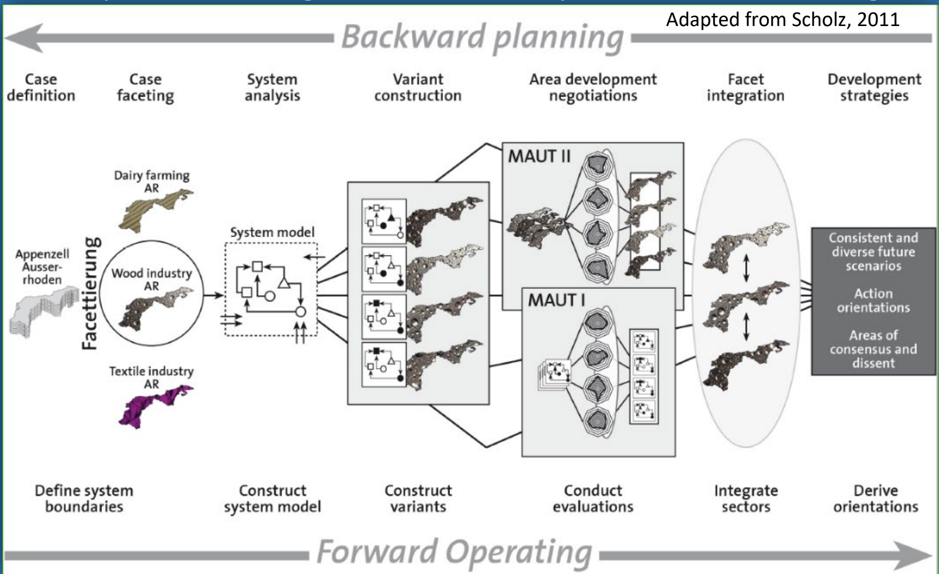
Complex problem structuring in transdisciplinary processes: Participatory tools for constructing and evaluating scenarios

2021

A deep understanding of the functionality of FSA x MCA modeling



A Handbook for the FSA x MCA tool including an adaptation/ implementation instruction

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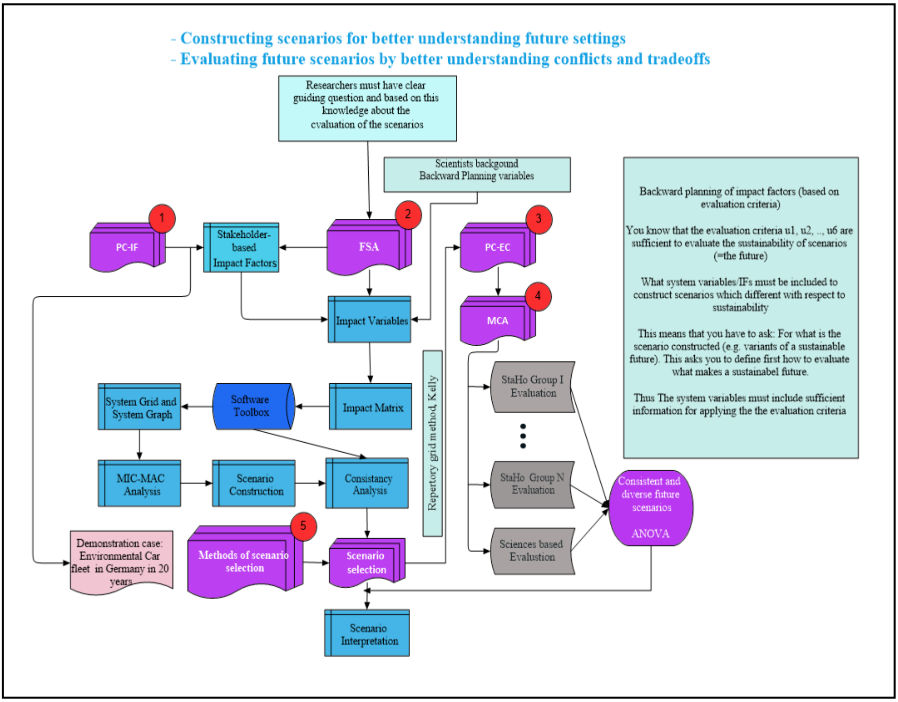
DiDaT

Digitale Daten als Gegenstand eines transdisziplinären Prozesses

V 0.95

FSA × MCA ROAD-MAP



Abbreviations

PC-IF	Participatory Construction of Impact Factors (System Variables)
FSA	Formative
PC-EC	Participatory Construction of Evaluation Criteria
MCA	Multi-Criteria Assessment (also called MAUT Multiattribute Utility Theory)
ANOVA	Analysis of Variance

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WHAT DO YOU FIND IN THE HANDBOOK AND WHAT NOT?

The construction of the scenarios and evaluation may be new for some readers. There are different methods for constructing scenarios and running evaluations. Thus, the handbook first,

- Describes the specific method used in the FSA×MCA method,
- Explains by the example of what research question can be dealt with,
- provide orientation/recommendation, what may be done, and how the result may be interpreted.

Second, the manual for applying the FSA×MCA tool on different operating systems is presented.

Third, if scenario construction and evaluation are done in a participatory manner, including one or more stakeholder groups, the multivariate statistic should be applied. At the end of the book, the reader find the chapter ***Auxiliary information about ANOVA.*** There are also some sections on statistical applications in the different chapters. All these applications can be done by different statistical software tools such as SPSS or R.

The construction of the method of the handbook is a work in progress. The present version 0.95 is not fully completed. You may find the newest version under the FSA×MCA tool.

Fouth, the handbook is written with the Demonstration Version of the Morocco Salidråa Oasis Management case in the background. For adapting the Progra to your own application e

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PARTICIPATORY TOOLS FOR CONSTRUCTING AND EVALUATING SCENARIOS

Roland W. Scholz & Paul Honore Takam
(First notes on getting access to the storyline of the FSA×MCA tool)

WHY: MOTIVATING QUESTIONS

- ✓ What are the options for the future? → Think about **scenarios**

- ✓ What are sustainable scenarios and what are unsustainable ones? → Think about **MCA**
- ✓ Do all stakeholders have an opinion on what is sustainable or not? Or: Does science and practice (practitioners) have the same judgment? →Think about **multi-stakeholder** evaluation (here "science" becomes one stakeholder)
- ✓ Should we include the stakeholders in the formation of scenarios? → Think about (a) stakeholder's **intuitive scenarios** and (b) that **stakeholders are the experts of impact factors** (they know what makes reality changing)
- ✓ By what criteria should the scenarios be evaluated? → Think about **measuring what criteria the stakeholders use** (e.g. Repertory Grid)
- ✓

RELATED FIELD OF SCIENCE

A contribution to the interface between

- ❖ Strategic sustainability management[1]

- ❖ Operational research
- ❖ Decision research (up to AHP)
- ❖

LIST OF METHODS

- Method 01: Stakeholders-based impact factors
- Method 02: Procedure/Steps of Formative Scenario Analysis
- Method 03: Stakeholder-based evaluation criteria
- Method 04: The procedure of multi-criteria assessment
- Method 05: Principles and strategies of scenario selection

PRODUCTS: **MANUAL**

Description of the methods

DESCRIPTION OF THE SOFTWARE TOOL

- How to get access
- Implementation (for what operational systems)
- User instruction for
    - Method 1
        - How a group of scientists may construct scenarios with the help of the FSA×MCA Tool
        - What outputs (graphs, figures) do the FSA×MCA Tool produce to support the scenario construction by a group
    - **Method 2**
    - **Method 3**
    - **Method 4**
    - **Method 5**

POTENTIAL RESEARCH QUESTIONS WHEN APPLY FSA×MCA

- What is a minimum sufficient set of scenarios which represents "essentially" different types of scenarios?
- If stakeholders formulate intuitive scenarios. How can we relate them to FSA scenarios?

CHAPTER1: PARTICIPATORY TOOLS FOR CONSTRUCTING AND EVALUATING SCENARIOS

Paul Honore Takam & Roland W. Scholz

INTRODUCTION

A transdisciplinary process on sustainable transitioning explores different variants or scenarios of the future of urban settings, the use of technologies, or modes of living. One challenge is to find and design scenarios that are sustainable and acceptable to all stakeholder groups. Another challenge is to identify consent and dissent between stakeholders; all stakeholder groups should best accept certain criteria of evaluation of scenarios. The combination of Formative Scenario Analysis and Multi-criteria assessment (FSA×MCA also called Area of development Negotiation (see Loukopoulos & Scholz, 2003) helps strategic planning groups to construct a well-defined set of scenarios and to collect data on different stakeholder group's evaluations for identifying consent and dissent among stakeholder groups. A *Formative Scenario Analysis* (FSA) means the involvement of the stakeholders in the process of constructing and evaluating possible future states of the case. The FSA includes the stakeholders, as real word system experts, in the construction and the evaluation of the scenarios. It provides a script describing steps that a study team must take in response to the current state and possible future states of a case. *A Multi-Criteria Evaluation* (MCA) is a hybrid. It is a method for analyzing and promoting case dynamics. Furthermore, it integrates different research areas and other methods of knowledge integration, particularly the Multi-Attribute Utility Theory (MAUT).

METHOD 01: STAKEHOLDERS-BASED IMPACT FACTORS (SYSTEM VARIABLES) [2]

IMPACT FACTORS FOR WHAT?

An **impact factor** (IF) is a **system variable** or a variable that serves as (case or system) **descriptor** ($i = 1, \dots, I$) of a real-world case. For FSA, a prerequisite and goal is to define a **small set** of IFs by which we can describe the

[2] The ideas of these chapters and some sections may be found in Scholz and Tietje (2002)

- **status quo** and the
- **changes** (i.e., the dynamics)

of a system according to a research question (guiding question) posed in the FSA. When applying the FSA we are following the **satisficing principle** (Simon, 1987). The construction must be "good enough" and sufficient for satisfyingly answering the research question. Another principle which we should have in mind is the parsimony principle, which means that the construction should be as simple as possible and use a minimum number of variables and functions[3].

The construction of **impact factors** is the most challenging, difficult, and time expensive part of an FSA. A major reason for that is that a construction of IFs have to be built on

- **research question (guiding question)** which a researcher or research team wants to get answered (and usually is not formulated in a sufficiently crisp manner)
- **meaningful system boundaries**, given the research question; system boundaries refer to **time**, **spatial**, and **content-related** constraints or dimensions (see below)

If an FSA is constructed for evaluating scenarios, the construction of IFs depends also on the

- **evaluation criteria**

which are applied for the scenarios? This is due to that the issue that the scenario description (which is done by the IFs) must include sufficient information for providing evaluation or assessment. This will challenge the scenario analyst the backward **planning principle** in some way (see below).

TYPES OF GUIDING QUESTIONS FOR FSA

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[3] Selecting a few important variables/indicators which really reprersent all informations in a suffissant manner Egon Brunswik theory of probabilistic functionalism. How this can be apply to scenario constructions is discuss in.

In principle, there are three types of questions involved in the scenario construction. We distinguish between:

1) **How may the future look like? An exploratory investigation** of what types of scenarios may become possible in the future. This question is often posed in the way of "The FSA is used for describing all future states." This is naïve as the set of IFs is only a small number of system variables that cannot sufficiently describe the funnel of all possible future states of a complex real-world system.
2) **What is the best scenario? Finding the best scenario** from a certain perspective. This asks that the evaluation criteria are already known and defined. Please note, that a definition of an evaluation criterion includes a **content-dimension** (e.g., beautiful, expensive, sustainable, etc.) and scaling of the evaluation **criteria**.[4] Finding the best scenario is based on the comparison.[5] We can only avoid cyclic triads if we apply an interval scale.
3) **Comparative scenario evaluation between (members of) stakeholder groups or between a scientific reference evaluation and stakeholder groups' evaluation** to measure consent and dissent[6] of scenario evaluation. This means that (usually) based on evaluation (criteria)-based judgments of stakeholders, the research questions targets:

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[4] Evaluation criteria can have all levels of scaling from nominal (Does something exists? Yes or No) to absolute scale (temperature measured by Kelvin grades). Usually, evaluation criteria are of ordinal or interval scale.

[5] This implies that when constructing the evaluation criteria or method the scaling of the evaluation criteria must be considered, e.g. to avoid phenomena such as cyclic triads ($A > B > C > A$) as described by the Arrow paradox.

[6] Consent and dissent is assessed according to statistical significant differences in the judgment of stakeholder groups, e.g., on a certain evaluation criteria. If there is **no** statistical difference of the (mean) judgments of two groups, we talk about consent.

- What is the **most preferred scenario** across all stakeholder groups[7]
- **What stakeholder groups** $(SG_r, r = 1, \dots, R)$ **differ in evaluating** a set of scenarios $(S_s = \left(d_1^{n_{s,1}}, d_2^{n_{s,2}}, \dots, d_N^{n_{s,N}}\right), s = 1, \dots, n_S)$?
- For what **evaluation criteria** $(u_t, t = 1, \dots T)$ may we find significant differences in evaluation criteria (which may be interpreted as **tradeoff** among evaluation criteria on scenarios)
- If there are enough members (in general $n_r \geq 6$) in all stakeholder groups (and the evaluation criteria have the level of an interval scale), the comparisons can be analyzed by a multivariate repeated measurement analysis of variance (Bortz, 2005ANOVA;)
- If there is a single **scientific reference evaluation** that may provide an evaluation (e.g., along modeled and quantitatively assesses sustainability criteria) ANOVA allows to identify what stakeholder groups differ from the reference evaluation and in what criteria

A research question must be formulated along with the **Guiding Question**. The Guiding question includes a

- (Content related) **Perspective**, which represents the scenario analysts' interest (for instance efficiency, sustainability, costs, etc.).
- A **system boundary** concerning **time** and **physical boundaries**

[7] If we have only one stakeholder group und a set of scenarios, this can be done by a one-dimensional ANOVA. But also in multivariate ANOVAs (e,g., when considering a set of stakeholder groups which provide evaluation for scenarios and a set of scenarios) the main effect of a of the variable scenario provides information which is the best scenario. Usually, after the significance of the main effect has been assessed, you need a posterior text (Janssen & Laatz, 2016)

Examples of *perspectives* are making money, winning a military battle, building an attractive suburb or urban quarter for a former brownfield, developing sustainable agricultural techniques, constructing strategies for pandemic management, organizing robust and resilient energy supply, looking for sustainable car fleets, what is a most preferred lifestyle, etc.. Based on the perspective certain dimensions can be excluded (such as the cultural tradition of folk song, the educational system, military or secret services, etc.) IF have not to include information about the excluded dimensions. Thus, it is important to think about what I do not need as IF.
There is a wide range of perspectives ranging from planning **variants of planning** (FSA is a planning technique) to **strategic sustainability management**

Stakeholders are the **experts of the complex real-world system**. They have (analytic and intuitive) knowledge of how a system works. Thus experts have to be involved in the construction of the impact factors. This can be done simply by asking them in the frame of participatory processes.

APPROACHES AND FRAMES FOR CONSTRUCTING IMPACT FACTORS:

1. (Group) Mind storming, with Metaplan method, 2-dimensional clustering of impact variables
2. Look for subsystems: Ecol., econ., soc.,
3. Think about the last 20 years of big **planning projects**: Ask **why** they have been planned/discussed. Identifying
   - main external reasons
   - main drivers of stakeholder groups
4. Refer to a well-acknowledged system model:

- Supply-demand chain (if scenarios of market chains are focused)

5. Think in multi-scale scenarios/multi-scale impact factors

THEORETICAL FOUNDATIONS FOR CONSTRUCTING IMPACT FACTORS

There are three theoretical roots or basic assumptions underlying the identification of impact factors (IFs). The first is

1) Different groups of societal actors have **different types of knowledge and epistemic** (ways of knowing) about how reality works. This particularly holds for **scientists** and **practitioners**. Both are experts of a different type. Practitioners are experts for concrete real-world systems. Scientists are experts for abstracted systems.
2) There is an (epistemological) architecture of knowledge (see Figure 1) that allows distinguishing between experiencing (German: erfahren), understanding (verstehen), conceptualizing (begreifen), and explaining (erklären). The impact factors emerge from the level of "begreifen", i.e., the ability to identify subsystems, main drivers, etc. We call them facets and the process of identifying their **faceting**.

The question of how many IFs do we need is answered by **Brunswik's theory of probabilistic functionalism** (Hammond & Stewart, 2001; Scholz, 2017, 2018) who suggested

The system variables must be sufficient to describe the dynamics of changing according to your research question. Impact factors depend on the evaluation criteria. What are the proper system boundaries?

2-What is the research question?

a-What is a minimum sufficient set of scenarios that represents "essentially" different types of scenarios?

b-If stakeholders formulate intuitive scenarios. How can we relate them to FSA scenarios?

c-If I have my set of scenarios, how can we choose the most sustainable ones?

3-What impact factors/system variables for what research question.

4-If you think about the change of the system, what are the most important factors.

THE PRACTICAL SIDE: HOW TO CONSTRUCT/INQUIRE THE IMPACT FACTORS

An example of the Drâa valley case. For the Drâa case, we consider the following stakeholder groups: Municipal Authority, Health expert, Water management expert, Agriculture Expert, Native of Salidraa2, Non-native, and non-expert.

Means: Construct "action scenarios" (variants of political, economic, marketing, etc. actions which are combined with "planning variants")

Research question: How can the long-term management of the Draa valley towards the protection of its ecosystems and dependent livelihoods be achieved by 2030?

GUIDING QUESTIONS:

Question 1: If you look at the present state of the case, What are the important characteristics/ properties/ features/… concerning the case?

Question 2: If you look forward to the development and changes of Salidrâa in the next 10 years, what are the most important causes (factors, drivers, reasons) for a change of Salidrâa?

Question 3: If you look at the research questions and the list of Impact factors you provide in questions 1 and 2, what are the most important three?
The answers to these questions will help us build a list of Impact factors.
How to build a conjoint list of IFs from different participants
This is done manually by the study. After applying the PC-IF tool the study team gets many different lists from many stakeholders as an excel file and integrates them manually. The integration procedure is done in many steps:

- The study team merges the evident semantic to a common label of impact factors.
- They build semantic clusters ((according to “subsystems”; e.g. Water-input and management which may include a couple of IFs) when using colors.

While building the blocks the study team has to follow some general rules and take care of the colored table. They distinguish between IFs which are controlled/affected by different “systems” (e.g. naturally controlled IFs (e.g. precipitation, climate change) and human-controlled/management IF, etc.). After building the block the study team discusses the results in the group. At the end of the procedure, we obtain the following table of impact factors.

Table 1: Conjoint list of impact factors from Salidrâa team

Impact factors	definition	levels	Logical expla-nation	Reflection/dis-cussion
Dam re-lease/ dam manage-ment	Water released for agriculture pur-poses	High:> 250 Mm3/year release Low: < 250 Mm3 / year estimated release	High: this is the cur-rent re-lease and es-timated to fulfill the de-mand	Replaced water use. The amount of water released is a function of both water de-mand (of the Oa-sis farmers) and water availability in the dams. Wa-ter availability in the dam depends on precipitation and water ab-straction for drinking water, which has prior-ity over irriga-tion water
Agricul-tural land cover	Refers to all types of agricultural ac-tivities in the Draa valley. Increasing water demand is mainly driven by land extensions, but the land is abandoned due to water and soil problems or loss of human labour. Currently, ca 26 000 ha of land are cultivated on aver-age in the past 10 years	**High**: In-crease by 10 % **Low**: No change or decrease (%)		

Urban population growth	Percentage of urbanisation (total urban population in 2014 is 164 500)	**High**: an increase of 2 % **Low**: same or decrease of 2 %	from HCP from 2004 - 2014 the urbanisation in the region was 2%.	This will increase the drinking water demands in urban areas (relates directly to the dam releases)
Rural population growth	Number of inhabitants living in rural areas (in 2014 440 308 people were living in rural areas)	**High**: higher than the status quo **Low**: status quo, or less inhabitants		This will give some insights on the number of people being able to contribute to the maintenance of the oasis. (low rural population growth → who stays behind to maintain the system
Aridity	This impact factor describes the climate, in particular the relation between precipitation and evaporation	**High:** increasing aridity score by 5% **Low:** same climate		
No of tubewells	Indicates the abstraction of groundwater. Wells are mostly shallow whereas tubewells are deep and reflect the	**High:** >10’000 **Low**: No change or decrease in		Is influenced by need (absence of surface water), but also by salinity and the ability to access groundwater through

	dropping ground-water levels. ~10'000 (wells with motor pumps) in 2011	water abstraction and wells		technology: Wells, pumping technology, etc.
Salinization	Salt concentration or conductivity in water and consequently in soils (µS/cm; g/L; g/kg of soil)	High: **Increasing** Low: **No change**		Plays an important role in drinking water and agriculture. This could be a critical factor for achieving sustainability
Agricultural subsidies	Number of farmers benefiting from subsidies	**High**: > … Increase in the number of beneficiaries planned in the subsidies program **Low**: < …. no change or decrease in the number of beneficiaries		Farming in the extensions (outside of the traditional oasis) is partly possible through the access of different subsidies (for drip irrigation; installation water basin; …)
Quality of life	People feel satisfied with their living conditions.	High: **High satisfaction** Low: **No satisfaction**		

Integrating Impact Factors of different experts from science and/or stakeholder groups

METHOD 02: PROCEDURE/STEPS OF FORMATIVE SCENARIO ANALYSIS

A Formative Scenario Analysis (FSA) is a scientific technique to construct well-defined sets of assumptions to gain insight into a case and its potential development. The FSA provides a script describing steps that a scenario analysis must take in response to the current state and possible future states of a case.

Scenarios are representations of alternative futures that help to explore the space of possible futures. Each scenario is one alternative representation of how the future might unfold. This is done by introducing so-called impact factors.

An impact factor (also called system variable or impact variable) is simply a variable that describes the current state and dynamics of the case. The art of scenario analysis consists of creating a sufficient set of impact variables and linking them in such a way as to gain a valid case description. A scenario may contain qualitative and/or quantitative statements. The Formative Scenario Analysis procedure guides the scenario analysts toward a differentiated and structured understanding of a case's current state and its dynamics. It is usually performed by small groups with specialized expertise about different aspects of the case, which they share. In Formative Scenario Analysis, a scenario is formally defined by a combination of levels of all impact factors. A Formative Scenario Analysis is a nine-step procedure (Scholz & Tietje, 2002, chapter 9) that should be worked through sequentially. When describing the method, we will refer to the Environmental Car Fleets case study in Germany in 20 years.#

STEP 1: CASE AND GUIDING QUESTIONS

First, the study team must find a clear answer to the question "What is the case?" Many cases have fuzzy margins. In the case of the Environmental Car Fleets case study, we have to clarify whether or no the buses are part of the case. It is best to specify the time and space limitations of a case. This is done by providing a clear definition of the case.
Second, a specific perspective on the outcome of the case analysis must be determined. The critical question for this step is "Why is the scenario analysis being performed?" The answer to this question will define the future states of the case.

In the case of Environmental Car Fleets in Germany in 20 years, we wanted to determine which future realizations of the case might be judged sustainable.

Note that different outcomes require completely different system variables. It is important for the future of a case to reflect on both the larger context in which development takes place (i.e., its frame, or shell) and the inner case activities and developments. Constructed sets of possible outcomes of these local variables are called variants. The combination V_m x S_k the variants, V_m with the shell scenarios, S_k is labeled $set_{m,k}$. Within Formative Scenario Analysis, scenarios act as independent variables, and the evaluations are considered dependent variables. Formally, the scenarios are denoted S_k and the evaluations $v(S_k)$. Scenarios are considered independent because the study team is free to construct a scenario in the domain of future possible states of the case. However, given a well-defined scenario, an evaluation of it is completely determined, making it a dependent variable (see Hays, 1963, p. 39).

STEP 2: SYSTEM PROPERTIES

The scenario analyst must mentally delve into the case to determine the factors that establish the current state of the case and its dynamics. There are two proven strategies for determining these crucial factors. One strategy is to perform a plus-minus analysis. It is important to perform separate plus-minus analyses because what may be considered strengths from an economic perspective might be considered weaknesses from a social or environmental perspective. Thus, two or more plus-minus analyses should be performed. The more extended version of the plus-minus analysis is the Strengths-Weaknesses-Options-Threats (SWOT) analysis, which also can be conducted at this step of Formative Scenario Analysis.

Another strategy is to study formerly planned projects or interventions. Usually, several plans for improving the case already have been proposed. Each plan generally provides insight into the structure and dynamics of the case, highlighting the case's potential while revealing sensitive features and factors (impact variables) that could have an impact on case development.

STEP 3: IMPACT VARIABLES

This step aims to develop a set of impact variables sufficient for valid description and modeling of the current state of the case and its dynamics. The impact variables, formally defined as d_i, $(i = 1, \ldots, N)$ are also called system variables, impact factors, or case descriptors.

We use the letter d because impact variables also act as **descriptors** of future states of the case. To answer the question "What are the most decisive factors for the Environmental Car Fleets case? First, three different domains of impact variables are determined: society, economics, and the environment. Then, a shortlist of potential impact factors is considered (see Table 1) below. The best way is to consider a long list of potential impact factors in a brainstorming session or interview and condense it into a shortlist of items. In this step, the reference to state-of-the-art knowledge is required. For each impact variable, the study team can create a crisp definition. One good way of doing this is to provide a one-page description. One impact factor for the Environmental Car Fleets case could be the Modal split, defined as the percentage share of each mode of transport in total inland transport, expressed in passenger-kilometers (pkm). This impact factor has two levels (high vs. low)

NOTE: The construction of impact variables is the most important step in the whole process of Formative Scenario Analysis. It corresponds to the construction of perceptors in the Brunswikian Lens Model (see Scholz & Tietje, 2002, Figure 9.2).

STEP 4: IMPACT MATRIX

The formation of an impact matrix initiates the actual synthesis process. Once the impact variables have been defined, the impact matrix can be constructed very easily. An impact matrix looks like a table in which the first row and the first column are filled with names of impact variables and the remaining cells with the numbers representing the impact strength between them. The last row and the last column of the table give the activity and the passivity of the impact variable, respectively. The activity of a variable (i.e., the extent to which a variable's impact on other variables is active), d_i is the row sum of all of the impacts that this variable has on all other variables $\mathrm{d_j}$.

The sensitivity/passivity of a variable, d_i is calculated by summing up the cells of column i, that is, the impacts that all other variables have on it. The sensitivity is correlated with the medium dependence of a variable on other variables.

Impact strength: If we calculate the ratio between activity and sensitivity, we get a summary indicator of the medium impact strength of a variable on the case.

The impact matrix is formally defined as $\mathrm{A} = \left(\mathrm{a_{i,j}}\right)', \ \mathrm{i,j} = 1,\ldots,\mathrm{N}$. A cell, $\mathrm{a_{i,j}}$ of the matrix assigns (the absolute value of) the direct impact strength of one impact variable, $\mathrm{d_i}$, on another impact variable, $\mathrm{d_j}$ $(i \neq j)$.

The cells of the impact matrix provide information on how different system variables of a case are interrelated. The diagonal of the impact matrix is filled with zeros because the impact variable has no direct impact strength with itself.

In practice, the impacts should be rated on a 3- to 7-point scale, but within this range, no general rule exists that clarifies which scaling is the most appropriate. For example, the following three-level scale can be chosen: 0 =no or very little impact, 1 =medium impact, 2=high impact. A dichotomous 0-1 rating can be considered when transforming the ones to zeros and the twos to ones. For example, for the Environmental car fleets case study, the dichotomous 0-1 rating is considered where 0 = no or very little impact and 1= high impact strength. The impact matrix, in this case, is given in Figure 1.

STEP 5: GRAPHICAL REPRESENTATIONS: SYSTEM GRID AND SYSTEM GRAPH

This step provides a transformation of the information from an algebraic impact matrix to a geometrical system grid and system graph. This is done by appropriate software such as FSAxMCA we propose in this booklet. A system grid is a conjoint display of the column and row sums. Here, the impact variables are partitioned into four sets (active, passive, ambivalent, and buffer variables).

The variables that are above average in activity and below average in passivity are located in the Active quadrant, those which are above average in both activity and passivity are located in the Ambivalent quadrant, those which are both below average in activity and above average in passivity are located in the passive quadrant and those which are below average in both activity and passivity are Buffer variables.

For the Environmental car fleets case, the impact factor of Fossil fuels is considered as an active variable because it is above average in activity and below average in passivity (see Figure 2).

The system graph is a structured network that presents a structural view of the system model. It visualizes how the different variables are interlinked. This system graph is generated automatically by suitable software. If we enter the data into a suitable software program for networking (e.g., Krackhardt, Blythe, & McGrath, 1994), we get the graph like that in Figure 3 which provides a comprehensive insight into the study team's assessment of the relative importance and mutual relationships of all the variables.

STEP 6: MIC-MAC ANALYSIS

The goal of the MIC-MAC (Cross Impact Matrix-Multiplication Applied to Classification) Analysis is to take the indirect impacts into account to gain a more detailed insight into the impact variables' importance from a System Dynamics perspective. To take into account the indirect impacts, the impact matrix is multiplied with itself repeatedly, and after each multiplication, the column sums and row sums are calculated. If this has been done often enough, the rankings of the column and row sums mostly become stable.

The row sum is generally considered to be indicative of a variable's activity, including indirect impacts. Similarly, the column sum is indicative of a variable's passivity, including indirect impacts.

The scores of direct and indirect impact activity (or passivity) have to be compared. If a variable's scores for its indirect impacts are higher than those for its direct ones, one might conclude that this variable is of higher importance than the study team had supposed. For the Environmental car fleets case, we can say based on Figure 2 that the impact variable that plays the most active role in the future state of our case study is the Number of cars per thousand inhabitants, but if we take into account the indirect impacts, we may find out that the impact variable Fossil fuels play a more active role than number of cars per thousand inhabitants.

STEP 7: SCENARIO CONSTRUCTION

At this point in the analysis, it becomes apparent that scenario analysts should be parsimonious in defining impact factors and their levels from the very beginning. Even though at this step, the number of variables should be reduced out of the differentiated insight gained from the MIC-MAC Analysis. This can best be done by referring to the system grid and system graph (see Figures 2 and 3). If there are 3 impact variables and each of them has only two levels, we will have $2^3 = 8$ different scenarios. For each impact variable d_i, we have defined different levels $\mathrm{d}_\mathrm{i}^{\mathrm{n_i}}$, $(\mathrm{i} = 1, \dots, \mathrm{N_i})$. where $N_i \geq 2$ denotes the number of different levels that we have allowed for the impact variable d_i. The total number of scenarios is $\mathrm{k_0} = \prod_{i=1}^{N} N_i$, where N is the number of impact variables. Formally, a scenario, S, is simply a complete combination of levels of impact factors $(\mathrm{d}_1^{\mathrm{n}_1}, \mathrm{d}_2^{\mathrm{n}_2}, \dots, \mathrm{d}_\mathrm{N}^{\mathrm{n}_\mathrm{N}})$ for all factors $\mathrm{d_i}$, $(\mathrm{i} = 1, \dots, \mathrm{N})$

$$\boldsymbol{S} = (\mathrm{d}_1^{\mathrm{n}_1}, \mathrm{d}_2^{\mathrm{n}_2}, \dots, \mathrm{d}_\mathrm{N}^{\mathrm{n}_\mathrm{N}})$$

An impact variable's activity is the most decisive criterion of the selection procedure. For the Environmental car fleets case study we have 5 impact variables with 2 levels each (see Table 1), then we expect to have $2^5 = 32$ different scenarios.

SPET 8: CONSISTENCY ANALYSIS AND SCENARIO SELECTION

Consistency analysis is an analytical procedure for cleaning up a set of scenarios. Scenario selection is a two-step procedure for assessing possibility. First, we produce consistency measures for each scenario. These allow us to distinguish between consistent and inconsistent scenarios. Second, we have to screen this set of consistent scenarios to select a small number of scenarios that represent the set of future states of our case. The following is the procedure.

Let S_k be one scenario of the set of all possible scenarios $\{S_k\}$. For each pair of impact variables, a consistency measure

$$c(d_i^{n_i}, d_j^{n_j})$$

is assessed. the function $c(.,.)$ is a mapping from the set of possible combinations of impact variables into the space of (judged) logical inconsistencies. A scaling with few (three to four) levels is generally recommended. It is advantageous to penalize strong inconsistencies by giving them drastically low ratings. A consistency matrix that includes all combinations of levels of impact factors, has to be filled out by the study team. This matrix is defined as

$c = c(d_i^{n_i}, d_j^{n_j})$.

In general, a consistency matrix looks like an impact matrix, but the first row and the first column are filled with the levels of impact factors, and the remaining cells are filled with the rates assigned to each combination of impact variables with a consistency measure defined above.

The value that assigns a conjoint consistency measure for each scenario is given by

$$c^*(S_k) = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} c(d_i^{n_i}, d_j^{n_j}) \,.$$

There are also other consistency values offered in the scenario analysis literature (see Missler-Behr, 1993, p. 33). There are several computer programs available for consistency analysis, but this can also be done easily with spreadsheet software.

Of course, no specific rules define when a scenario is consistent, but various techniques are commonly used (see Scholz & Tietje, 2002, page 108).

STEP 9: SCENARIO INTERPRETATION

There are many ways of interpreting scenarios (see Scholz & Tietje, 2002, chapter 9). Here we describe four of them: conversation, evaluation, best reply strategies, and scenario manipulation.

Conversation. The most natural way of interpreting scenarios is by simply discussing them-their differences, their genesis, and their quality concerning certain criteria and perspectives. Scenario descriptions should provide concise patterns to facilitate a much more elaborate discussion of possible future states than had been possible before the analysis.
Evaluation. Evaluation can be thought of as a specific form of interpretation. but there are both soft and hard methods of evaluation.

The evaluation is soft if the criteria and procedure for evaluation are not explicitly revealed, but rather are implicitly involved in the inferences and conclusions and we consider an evaluation procedure hard if the criteria and procedure are made explicit. As an example of a hard method, the Multi-Attribute Utility Theory is a highly formative procedure of scenario evaluation (see Scholz & Tietje, 2002, chapter 11).

Best Reply Strategies. Another way of working with scenarios is to think about which intervention or strategy would be the best for the case in response to a certain scenario. A well-known robust strategy is a max-min strategy. This strategy presumes that, for all the possible intervention options (i.e., variants), the worst global scenario will occur. Under this (pessimistic) assumption, the maximizing variant is chosen. Formally, if the value function is $v(.)$, then for each scenario S_k, the max-min strategy is given as $\max_m \min_k \{v(set_{m,k})\}$.

Scenario Manipulation. One way of understanding a scenario is through studying and interpreting it by manipulating the impact strengths. This manipulation provides information about the sensitivity of the case structure and, therefore, where the case can be affected.

DEMONSTRATION CASE FOR FORMATIVE SCENARIO FORMATION

In this section, we present a simple example just to show how a *formative scenario analysis* and *multi-criteria analysis* are working.

GOAL AND SCOPE OF THE CASE STUDY.

For this example, we choose the case to be the **Environmental Car Fleets in Germany in 20 years.**

This is motivated by the idea to evaluate different variants of car fleets in 20 years and we will look at the typical sustainability criteria such as environmental protection and emission. One has to answer the following question: given the energy transition in Germany, how do the environmental impacts of the German passenger car fleet look like in 20 Years? In general, *car fleets* or fleet vehicles are groups of motor vehicles owned or leased by a business, government agency, or other organization rather than by an individual or family. Typical examples are vehicles operated by car rental companies, taxicab companies, public utilities, public bus companies, and police departments. For the case of demonstrating scenario building, a car fleet can be pragmatically defined as all passenger cars (used privately or commercially). A *passenger car* is a road motor vehicle, other than a moped or a motorcycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver). Included are: Vans designed and used primarily for the transport of passengers, Taxi, Hire cars, Ambulances, Motor homes, Micro-cars (needing no permit to be driven). Excluded are light goods road vehicles, as well as motor coaches and buses, and mini-buses/mini-coaches.

Table 1. Environmental and socio-economic impact variables for the case study

Impact variables	Short description	Levels
Number of cars per thousand inhabitants	In 2017, 561 passenger cars per thousand inhabitants were recorded	d_1^1 = high > 500cars d_1^2 = low < 500 cars
Modal split	The most preferred transport *mode* based on the share of pkm traveled in 2017 was passenger cars, with a share of 84.2%.	d_2^1 = high > 60% d_2^2 = low < 60%
Low CO2 emission	*The average* CO_2 emissions by passenger cars are around 120 g/km	d_3^1 = high >95 g/km d_3^2 = low < 95 g/km
Fossil fuel cars	in 2017, 65% of passenger cars were petrol engines and 32,8% diesel. According to Eurostat	d_4^1 = high > 60% d_4^2 = low < 60%
Alternative fuel cars	Include electricity, LPG, natural gas alcohols, mixtures of alcohols with other fuels, hydrogen, biofuels are around 1.35%.	d_5^1 = high > 50% d_5^2 = low < 50%

IMPACT VARIABLES.

To answer the question "What are the most decisive factors for the environmental car fleets in Germany regarding the sustainable environment?" First, three different domains of impact variables are determined: society, economics, and the environment. Then, a shortlist of potential impact factors is considered (see Table 1.1) below. For each impact factor, we provide a short description and

two levels (low and high) and we describe what we mean by low and high.
Modal split: the percentage share of each mode of transport in total inland transport, expressed in passenger-kilometers (pkm).
Alternative fuels: the type of motor energy other than conventional fuels, petrol, and diesel.

IMPACT MATRIX

For the case study, the following dichotomous 0-1 scale is chosen: 0 = no or very little impact, 1 = high impact. The impact matrix (see Figure 1) has to be filled with reasonable values. The cells of the matrix are the impact strength between variables. Activity refers to the sum of the impacts that one variable, d_i, has on every other variable, d_j, $(i, j = 1, \ldots, N,\ i \neq j)$ and Passivity reflects the impacts that all the other variables, d_j, have on d_i. The last column and the last row indicate the activity and the passivity of each impact variable, respectively.

	Number of cars	Modal split	CO2 emission	Fossil fuels	Alternative fuels	
Number of cars	0	1	1	1	1	4
Modal split	0	0	1	0	1	2
CO2 emission	1	0	0	1	1	3
Fossil fuels	1	0	1	0	1	3
Alternative fuels	1	0	1	0	0	2
	3	1	4	2	4	

Figure 1: Impact matrix for the car fleet case study

SYSTEM GRID AND SYSTEM GRAPH

In Figure 2, the plane is divided by a vertical and a horizontal line through the mean activity and sensitivity/passivity scores. Hence, the impact variables are partitioned into four sets.

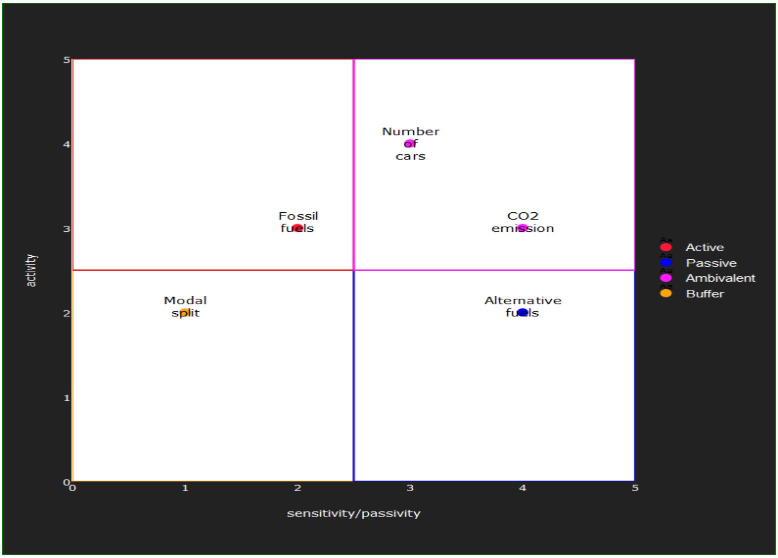

Figure 2: System Grid of the Activity and Sensitivity/Passivity Scores.

The variables Number of cars and CO2 emission are considered above average in both sensitivity and activity, which places it in the Ambivalent quadrant. The variable Fossil fuels are above average in activity and below average in passivity; It is located in the Active quadrant. In contrast, the variable Alternative fuels are in the Passive quadrant because it is below average in activity but above average in passivity. Finally, the variable Modal split is called Buffer Variable because it is below average in both activity and sensitivity/passivity.

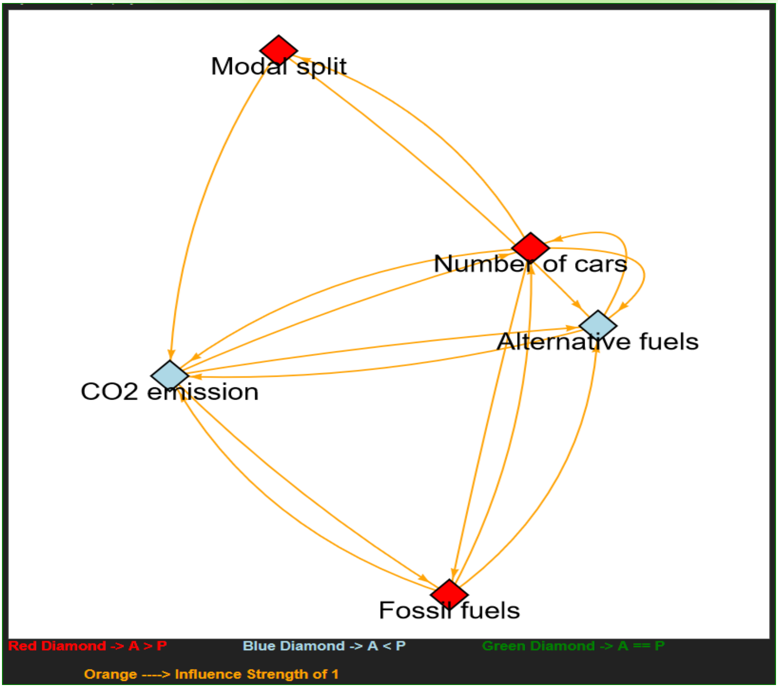

Figure 3: System Graph of the Impact Matrix of car fleet case study

Red diamonds have a higher active sum than passive sum; blue diamonds are the opposite

The system graph visualizes how the different variables are interlinked. Only strong impacts are displayed to prevent information overload. The impacts that a variable receives from other variables are indicated by arrows pointing to this variable. The impact of the variable on other variables is indicated by the arrow from this variable. Figure 3 shows that the number of cars per thousand inhabitants has a great impact on all the other variables and receives impacts from all the other variables too. We can say that the variable Number of cars plays the most active role in the future states of the case, but the MIC-MAC analysis has to be done to confirm our conjecture from the graph.

CONSISTENCY ANALYSIS AND SCENARIO SELECTION

For the car fleet case study, we have 5 impact factors/variables with 2 levels each. Therefore, we expect 32 distinct scenarios. We have to clean up the set of 32 scenarios to select 6 to 10 most consistent scenarios. This process is called consistency analysis. As defined above, a scenario is a combination of levels of impact factors. Let S be the set of all possible scenarios. For each scenario S_k a consistency measure c is applied. We define the rate as follows:

$c(.,.) = 2$	complete consistency, the combination of levels can be reasoned.
$c(.,.) = 1$	partial or weak consistency
$c(.,.) = 0$	inconsistent
$c(.,.) = -99$	strong inconsistency

Table 2. Consistency matrix for environmental car fleet case											
		d_1^1	d_1^2	d_2^1	d_2^2	d_3^1	d_3^2	d_4^1	d_4^2	d_5^1	d_5^2
d_1^1	high(1): Number of cars > 500	-	-	2	0	1	1	2	0	1	2
d_1^2	Low(2): Number of cars < 500	-	-	0	2	0	2	1	2	0	1
d_2^1	high(1): Modal split > 60%	-	-	-	-	1	1	2	0	1	2
d_2^2	low(2): Modal split < 60%	-	-	-	-	0	1	0	1	0	1
d_3^1	high(1): CO2 emission > 95 g/km	-	-	-	-	-	-	2	0	0	1
d_3^2	Low(2): CO2 emission < 95 g/km	-	-	-	-	-	-	0	1	0	2
d_4^1	high(1): Fossil fuel cars > 60%	-	-	-	-	-	-	-	-	-99	0
d_4^2	Low(2): Fossil fuel cars < 60%	-	-	-	-	-	-	-	-	2	0
d_5^1	high(1): Alterna-tive fuels > 50%	-	-	-	-	-	-	-	-	-	-
d_5^2	Low(2): Alterna-tive fuel < 50%	-	-	-	-	-	-	-	-	-	-

Please do not look at the numbers in this table but just try to get the idea since the rates are assigned randomly.

Table 3: Spreadsheet of scenario selection						
	NC	MS	CO2 E	FFC	AFC	Consistency Values $c^*(S_k)$
	H(0), L(1)	H(0), L(1)	H(0), L(1)	H(0), L(1)	H(0), L(1)	
S_1	0	0	0	0	1	15
S_2	0	0	1	0	1	14
S_3	1	1	1	1	1	13
S_4	1	0	1	0	1	11
S_5	0	0	1	1	1	11
S_6	1	1	1	1	1	11
S_7	1	0	1	1	1	11
S_8	1	0	0	0	1	10
S_9	1	1	1	0	1	10
S_{10}	0	1	0	0	1	9
S_{11}	0	1	1	1	1	9
S_{12}	0	0	0	1	1	9
S_{13}	0	0	1	1	1	9
S_{14}	1	0	1	1	0	9
S_{15}	0	1	1	0	1	9
S_{16}	1	1	0	1	1	8
S_{31}	0	1	1	0	0	-94
S_{32}	1	1	0	0	0	-94

NC: Number of cars; MS: Modal split; CO2 E: CO2 emission;
FFC: Fossil fuel cars; AFC: Alternative fuel cars; H: High; L: Low.

INTERPRETATION

The scenarios are numbered according to their consistency ranking. The higher the consistency value the most important is the scenario. The selection of the scenario is based on its consistency value. Here we can decide to choose the most consistent 7 scenarios. Scenario 1 denoted here by $S_1 = (0,0,0,0,1)$ can be interpreted as follows:
in 20 years in Germany, the (i) number of cars per 1000 inhabitants will be above 500, (ii) the percentage share of each mode of transport in total inland transport, expressed in passenger-kilometers will be above 60%, (iii) the CO2 emission in gram per kilometer will be above 95 g/km, (iv) the percentage of fossil fuel cars fill be above 50% and (v) the percentage of alternative fuel cars will be below 50%.

METHOD 03: STAKEHOLDER-BASED EVALUATION CRITERIA

EVALUATION CRITERIA FOR WHAT SCENARIOS?

The construction of the **evaluation criteria** is the most challenging, difficult, and time expensive as the construction of impact factors. A major reason for that is that a construction of evaluation criteria have to be built on

- **the research question (guiding question)** which a researcher or research team wants to get answered
- **meaningful system boundaries**, given the research question; system boundaries refer to **time**, **spatial**, and **content-related** constraints or dimensions (see below)
- **The small set of consistent scenarios.** The stakeholder should know the scenarios and should think about the question, what type of scenario should be presented and how can he/she evaluated them.

Types of guiding questions for the evaluation criteria. In principle, the evaluation can be constructed from the stakeholder view or the case goal view. The guiding question should be formulated concerning the view.

THE PRACTICAL SIDE: HOW TO CONSTRUCT/INQUIRE THE EVALUATION CRITERIA

An example of the Drâa valley case. For the Drâa River Basin case, we consider the following research question

Research question: How can the long-term management of the Draa valley towards the protection of its ecosystems and dependent livelihoods be achieved by 2030?

A small set of consistent scenarios. In the following table, we present a small set of scenarios.

Scenarios		S1		S2		S3		S4	
		Description	Code	Description	Code	Description	Code	Description	Code
1	Dam release	> 250mm3 per year	1	<250mm 3 per year	0	< 250mm3 per year	0	>250mm 3 per year	1
2	Agricultural land cover	Increase by 10%	1	Increase by 10%	1	Decrease by 10%	0	Decrease by 10%	0
3	Agricultural subsidies	Increase by 20%	1	Decrease By 20%	0	Decrease By 20%	0	Decrease By 20%	0
4	Quality of life	High	1	Low	0	High	1	Low	0
5	Aridity	Low	0	High	1	High	1	Low	0
6	Salinization	Low	0	High	1	High	1	Low	0
7	Rural population	Increase by 15%	1	Decrease by 15%	0	Decrease by 15%	0	Decrease by 15%	0
8	Number of tubwells	Increase by 20%	1	Decrease by 20%	0	Decrease by 20%	0	Decreases by 20%	0
9	Urban population	Decrease by 15%	0	Increase by 15%	1	Decrease by 15%	0	Increase by 15%	1
			The good change		**A change to the worse**		**The Unexpected change**		**The reversed change**

Figure 4: Scenarios selected to evaluate

NOVELISTIC CASE DESCRIPTION OF THE SCENARIO “THE GOOD CHANGE” OF THE DRÂA RIVER BASIN (S1)

The Drâa region’s water management and related decisions have been through a remarkable change. Regional actors in charge are tending to try new ways to increase the water supply in the area. In the Middle Drâa Valley, where six oases are aligned from the north to the south, local populations have been increasing for the last 5 years (7.1). Water supplied to this valley, through the Eddahbi dam, is two times more than the quantities supplied in the last years (1.1). This is factor number one supporting people to stay in the oases. The precipitation in the area is an additional factor for that. Farming activities have been increasing. As a result, there has been an extension of the agricultural lands (2.1), which was supported and promoted by the governmental institutions in charge at a regional scale (3.1). Water flow in the river bed and the aquifers of the Valley contributed, on one hand, to a less concentration of salt in the water and soils (6.0) and on the other hand, the level of aridity tended to decrease and its effects on lands were less visible (5.0). Revenue-generating activities are more present in the area, and the ratio of local populations satisfying their daily expenses and subsistence needs is high than in the previous years (4.1). The area was suffering from water scarcity and the aquifers were exploited intensively. However, it is still the case despite the availability of more water than before (8.1). In the years of droughts, the area has known, people tended to abandon their lands and houses. However, with the situation improving, most of them tend to go back to the oases and their farming lifestyle (9.0).

NOVELISTIC CASE DESCRIPTION OF THE SCENARIO “THE CHANGE TO THE WORSE” OF THE DRÂA RIVER BASIN (S2)

Climatic variability is taking over the measures and policies of water management in the Middle Drâa Valley. The Drâa river is experiencing a severe state of droughts. Water resource development and the different infrastructures, from which the aim was to satisfy the water needs of the area, are instead having a bad performance (1.0) and severely affecting the natural availability of water. Local populations in the valley are still trying to keep practicing farming, and tend to work more lands (2.1), mostly outside the oases or the extensions. Therefore, governmental institutions are promoting fewer activities than before (3.0). Less water flows from the Dam and the absence of precipitations will contribute to an increase in salt concentration in water, as well as soils (6.1), which is leading to severe aridity in the area (5.1). The aquifers are mostly dry (8.0). These are all factors leading to increasing rates of immigration among local populations (7.0). With fewer opportunities to have proper agricultural production to satisfy the daily needs and expenses (4.0), people chose to go to cities, where they can have new job opportunities and a decent life for their household members (9.1).

NOVELISTIC CASE DESCRIPTION OF THE SCENARIO "THE UNEXPECTED CHANGE" OF THE DRÂA RIVER BASIN (S3)

The Drâa region's dams are not well functioning, because of the weak precipitations in the area and the weak water volume stored (1,0). Consequently, the high levels of Aridity (5,1) and salinization of surfaces (6,1), affected badly the agricultural land cover in the area (2,0), and the lands are no longer useful for agricultural usages. In this sense, the government finds it hard to subsidize farming activities (3,0) in this situation where the probabilities of producing any crops are low. Most of the aquifers got consequently dry (8,0) and can't provide enough water to cover the loss of surface water. In this situation, most of the people chose to leave the area, either the valleys (7,0) or the two big cities Zagora and Ouarzazate (9.0), to go and find work opportunities in big cities out of the region. The people remaining in the valleys are trying to get through the days, with the few resources remaining there. With the rural population decrease, the few resources are now enough to have a good daily life (4,1), probably because of some water springs found in the area, or even transporting water from areas where it exists.

NOVELISTIC CASE DESCRIPTION OF THE SCENARIO "THE REVERSED CHANGE" OF THE DRÂA RIVER BASIN (S4)

The unstable and fluctuating situation of water in the Drâa River Basin had as a consequence the local population leaving the valleys for good (7,0), not only that, but it pushed them to replace their farming activities with other activities that are long-lasting and that can guarantee a stable income. For this reason, the agricultural land cover is decreasing (2,0), and people are no longer asking for agricultural subsidies (3,0) but another type of activity such as construction and commerce, taking place in cities of the area (9,1). Water is available (1,1), surface water, and groundwater, but it is mostly used for domestic usages, construction, but not essentially for agriculture. Water availability helped to reduce the aridity of the area (5,0) and the salinity of the surfaces (6,0). Also, the exploitation of aquifers decreases (8,0) and people are no longer investing in digging wells as before. The population chose to make their living from other stable activities, and they no longer trust investing time and energy in farming and not get anything in return. The alternative activities are ok but are not contributing to providing a good daily life (4,0), but at least they guarantee a fixed income for the households.

The evaluation criteria will be constructed based on the novelistic description of the scenarios.

GUIDING QUESTIONS:

From your perspective,

Question 1: if you want to evaluate the scenario "the good change" of the Draa river basin, what criteria are important?

Question 2: if you want to evaluate the scenario "a change to the worse" of the Draa river basin, what criteria are important?

Question 3: if you want to evaluate the scenario “the unexpected change” of the Draa river basin, what criteria are important?

Question 4: if you want to evaluate the scenario “the reversed change” of the Draa river basin”, what criteria are important?

Question 5: If you look at the research questions, the novelistic description of the scenarios, and the list of evaluation criteria you provided in questions 1, 2, 3, and 4, what are the most important 6?

The answers to these questions will help us build the list of evaluation criteria.

PAIR-WISE COMPARISON OF 3 RANDOMLY SELECTED SCENARIOS

To avoid the redundancy effect, we select randomly three scenarios out of 4 and make the pair-wise comparison.

Question 6: In what criteria does scenario 1 differ from scenario 2?

Question 7: In what criteria does scenario 1 differ from scenario 3?

Question 8: In what criteria does scenario 2 differ from scenario 3?

Question 9: In what criteria does scenario 1 differ from scenario (2,3)?

Question 10: In what criteria does scenario 2 differ from scenario (1,3)?

Question 11: In what criteria does scenario 3 differ from scenario (1,2)?

How to build a conjoint list of evaluation criteria from different participants

This is done manually by the study. After applying the PC-EC tool the study team gets many different lists from many stakeholders as an excel file and integrates them manually. The integration procedure is done in many steps:

- The study team merges the evident semantic to a common label of evaluation criteria.
- They build semantic clusters ((according to "subsystems") when using colors.

While building the blocks the study team has to follow some general rules and take care of the colored table. After building the block the study team discusses the results in the group. At the end of the procedure, we obtain the following table of evaluation criteria.

Environmental:

- U1 for local environmental impact assessment (EIA)
- U2 for (Global) LCA score (or energy/climate indicator)

Economic:

- U3 for Local income assessment (local economic performance) and distribution of income to different stakeholder groups of the site/case (social justice)
- U4 for "Global": contribution to national GDP

Social:

- U5 for local satisfaction of residents and resilience of the system
- U6 for stabilizing/destabilizing role in the supra-system (e.g. Morocco in the case of the Salidraa).

METHOD 04: THE PROCEDURE OF MULTI-CRITERIA ASSESSMENT

Multi-Criteria Evaluation (MCA) is a hybrid. It is a method not only for analyzing case dynamics but also for promoting them. Furthermore, it integrates different research areas and integrates other methods of knowledge integration, particularly Multi-Attribute Utility Theory or Life Cycle Assessment (Spielmann & Scholz, 2005)The latter is used to develop reference evaluations that allow for the identification of misperceptions. The MAUT is a label for a family of methods. These methods are a means of analyzing situations and creating an evaluation process (Scholz & Tietje, 2002). The objective of MCA is to attain a conjoint measure of the attractiveness (utility) of each outcome of a set of alternatives. Thus, the method is recommended when prospective alternatives must be evaluated to determine which alternative performs best. MCA decomposes the overall attractiveness (von Winterfeldt & Edwards, 1986) of an alternative into several attributes. Attributes are preference-related dimensions of a system.

WHAT HAPPEN IN MCA

The functional relationship between the system variables, their utility, and the weighting of the attributes depends on individual representations and subjective values.

The application of MAUT may answer several important questions:

- What is the specific structure of the case evaluation? How are the different evaluation criteria integrated?
- Which part of an evaluation should be substantiated by a scientific Assessment, and which part should rely on individual preferences?
- What are the preferences of the most important stakeholders?
- Which misperceptions or pitfalls may be found in the evaluation and decisions of the case agents?

When applying MAUT, the study team should have the following:

1. Sufficient problem/system/case knowledge, to realize

whether decisive attributes have been overlooked, are not well-defined (depend on each other), or overlap
2. A user model that describes what the user knows, which questions he or she can answer, and which interests may bias his or her evaluations
3. Knowledge about the appropriate level of graininess-in particular, preventing the application of an overly detailed or aggregated procedure
4. Good acceptance from the applicants, a relationship free of mistrust that allows the fear of being instrumentalized or of losing control of oneself when participating in a computer-controlled session to be overcome
5. Suitable technology, including a convenient, robust, user-friendly computer interface and an appropriate algorithm for modeling the evaluation

ATTRIBUTE RATING AND ATTRIBUTE WEIGHTING

The utility serves as a subjective measure for the attractiveness of the outcomes (consequences) of an alternative (von Winterfeldt & Edwards, 1986). The alternatives exhibit partial utilities concerning each of the different attributes. The attributes are aspects that are considered relevant for the evaluation. They may be considered objectively measurable or may be assessed subjectively.

In all instances, each attribute has two functions: It is part of the case description, and it is part of the perception of the agent who evaluates. State variables of the case are the origin. These variables constitute different attributes that are transformed to the utility (attractiveness value) scale and then aggregated to calculate the overall utility using a composition rule. The starting point for decision analysis is defining the problem, the objectives, the system under consideration, and the people whose evaluations are going to be investigated, all of which influence the possible results of the application.

The next important step is to define which alternatives are available in the decision situation or which states of a case shall be evaluated alternatively. Then, the alternatives have to be described by characteristic attributes (system variables describing the system state). Those variables that may be relevant for the evaluation and are different for the alternatives will be taken as attributes.

The set of attributes has to be sufficient, relevant, and available concerning the objectives.

WAYS OF APPLYING MCA

There are two ways of applying for MCA:

THE RESEARCHERS DEFINE THE EVALUATION CRITERIA

Standard procedure for sustainable transitioning of regional/urban systems

- Take the three "pillars" of sustainability as a starting point: environmental, economic, and social
- Take for each of the pillars a local and a global dimension, e.g.
    - Environmental: U1 for local environmental impact assessment (EIA) and U2 for (Global) LCA score (or energy/climate indicator)
    - Economic: U3 for local income assessment (local economic performance) and distribution of income to different stakeholder groups of the site/case (social justice) and U4 for "Global": contribution to national GDP
    - Social: U5 for local satisfaction of residents and resilience of the system and U6 for stabilizing/destabilizing role in the supra-system (e.g. Morocco in the case of the Salidraa.
- Define the variables in a way that the "performance" of the Scenarios can be rated on a "1-10 scale"

- Check the impact factors (and the table of levels of IFs) whether they include enough information to provide a reliable assessment of the scenarios according to U1 to U6 (backward planning)

THE EVALUATION CRITERIA ARE TAKEN FROM THE PC-EC METHOD

The second way is the same procedure as with the PCIF but the guiding questions are different.

In this procedure, the stakeholder has to

- Provide **scores** (0-10) for the criteria for all scenarios by answering the question: How good is/performs each Scenario concerning each criterion?
- Provide **weights** (1-10) to all criteria through the question: How important is the criterion for you if you evaluate the scenario?
- Define **minimum performance levels** (outranking thresholds) for all criteria.

After assessing the utilities of the alternatives and the weights of the attributes, we obtain the result given by the weighted sum

$u(S_k) = \sum_{j=1}^{J} w_j * u_{j,k}$ if $u_{j,k} > u_j(crit)$ for all j and

$u(S_k) = 0$ if there is a j with $u_{j,k} \leq u_j(crit)$

S_k is the scenario

k is the number of scenarios

u means utility, $j = 1, \ldots, J$

$u_j(crit)$ is the **minimum standard** of the quality of a scenario that becomes acceptable

$$w_j = \frac{w_{j'}}{\sum_{j'=1}^{J} w_{j'}}$$

$w_{j'}$ is the weighting score 1, 2, …, 10 (provide by the stakeholder) for a specific evaluation criterion j' and $0 < w_j \leq 1$ is the scaled weighting score with $\sum_{j=1}^{J} w_{j,k} = 1$ and J is the total number of criteria.

CHAPTER 2: MANUAL OF THE FSA × MCA SOFTWARE TOOL

METHOD 2: APPLYING THE SOFTWARE TOOL OF FSA

The goal of this manual is to describe (i) how to get access to the software tool, (ii) under which operating system it works, and (iii) how the FSA × MCA can be used to construct and to visualize scenarios,

The current version of the software we apply at this step of the FSA method was developed by Paul Honoré Takam based on a student-version of Thomas J. Lampoltshammer produced for scenario construction and scenario evaluation of organizational vulnerabilities (resilience) concerning digital threats (Scholz, Czichos, Parycek, & Lampoltshammer, 2020).

The software takes as input the impact matrix of impact factors from the and automatically and simultaneously generates the system graph and the system grid. The outputs of the software provide a comprehensive insight into the study team's assessment of the relative importance and mutual relationships of all the variables.

HOW TO GET ACCESS

The first current version of the software FSA × MCA is accessible offline and can be opened with any web browser such as Mozilla Firefox, Google Chrome, and the modern equivalent of Internet Explorer, Microsoft Edge. The web browser must first be installed locally on the computer. Then, the user of the software does not have to install the software on his computer since it comes with the executable file, which must be opened with one of the above web browsers.

IMPLEMENTATION

The software can be implemented in any operating system which supports the above-listed web browsers. For example, Google Chrome is supported by the following latest release version:

Windows , macOS & Linux 80.0.3987.116 / February 18, 2020;

Android 80.0.3987.117 / February 18, 2020;

iOS 80.0.3987.95 / February 10, 2020.

The Microsoft Edge is supported by the following latest release versions:

Windows & macOS 80.0.361.50 / February 11, 2020;

Xbox One 44.18363.8131 / January 7, 2020;

Android 44.11.4.4140 / January 19, 2020;

iOS 44.11.15 / January 18, 2020;

Depending on the operating system, the user must know first which web browser is available for his/her operating system.
The FSA × MCA software does not work with the old versions of Internet Explorer

SCENARIOS VISUALIZATION USING THE SOFTWARE: SYSTEM GRID AND SYSTEM GRAPH

Currently, the software consists of four modules: PC-IF, FSA, PC-EC, and MCA and the user has to choose the module according to what he/she wants to do.

When the user opens the software with an appropriate browser and clicks on “Formative Scenario Analysis” (FSA), a new window appears with two mains sub-modules (scenarios visualization and consistency analysis).

After clicking on sub-module “Scenarios Visualization”, a new window appears with two sub-modules (dichotomous scale 0-1 and three-points scale (0,1,2)), and the user has to choose the module according to the wanted two- or three-level rating of impact factors (see p. 26; impact strengths) After choosing the appropriate module, an interactive window appears (see Figure 5Figure 5) and the user is invited to enter the impact factors.

After typing the name of the impact factor (IF) and pressing the button “add new impact factor” in the interactive window (see Figure 5) or the button “enter” on the keyboard or on the bottom “Add Impact Factor”, the name of the impact factor appears in the table “Impact Factor Table” in the interactive window. Next to the button “Add Impact Factor” is the button “Delete Last Impact Factor”.

If the user enters the wrong name and wants to delete it, he/she simply presses the button “Delete Last Impact Factor”. When the new impact factor is added, it is added immediately to the impact factor table.

The user can insert the name of each impact factor one after the other. And he/she can rate immediately. The user may also or input the names of all the impact factors first and start putting the rate after the last impact factor.

Note: The impacts between factors have to be put directly in the impact matrix. At the end of the process, the impact factor table (see Figure 5) looks like Figure 6.

If the user wants to save the impact matrix as a CSV file or excel file, he/she simply presses the button “Export Impact matrix to CSV file ” or

“Export Impact matrix to Excel file” and the table will be saved automatically in the Downloads folder of his/her computer.

Later, the user may like to use the impact matrix he/she saved, he/she then simply press the button “Choose File” in the table “Import impact matrix”. Once the file is successfully imported, the system graph (see Figure 7) and the system grid (see Figure 8) appear automatically in the table “System Graph on the left | System Grid on the right”.

The system graph and the system grid are built gradually as the user inputs the rate of impact factors. The user can play with the rate of impact factors and visualize the system graph and system grid.

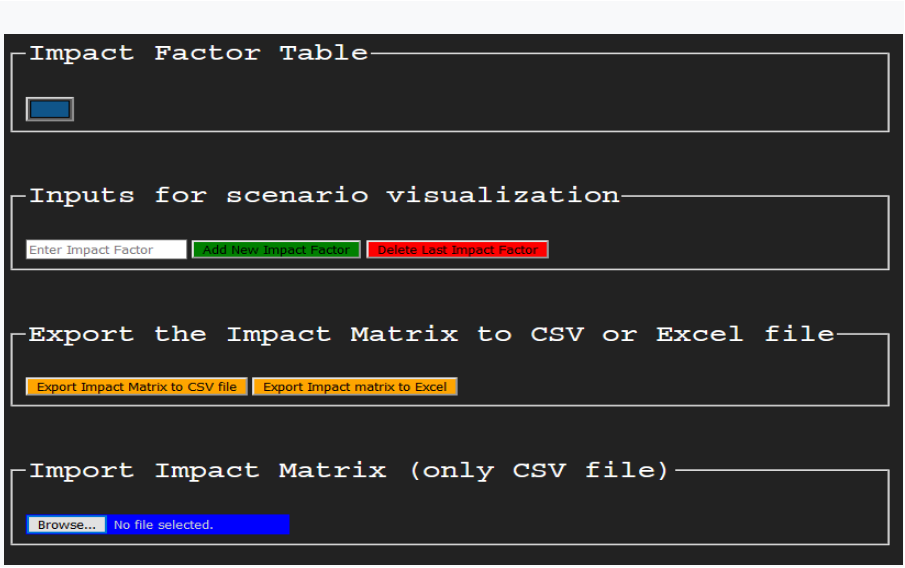

Figure 5: Interactive window ready to receive impact factors

Impact Factor Table

	Dam release	Agricultural land cover	Urban population	Aridity	Quality of life	
Dam release	0	2	1	2	2	7
Agricultural land cover	1	0	2	0	2	5
Urban population	0	2	0	2	0	4
Aridity	1	0	2	0	2	5
Quality of life	0	1	0	0	0	1
	2	5	5	4	6	

Figure 6: Impact factors' table

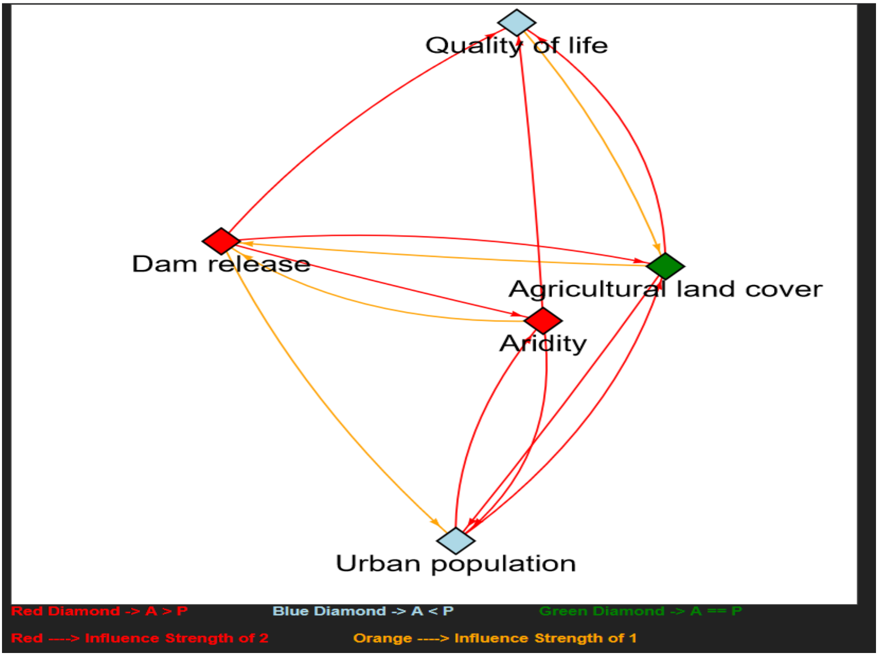

Figure 7: System graph

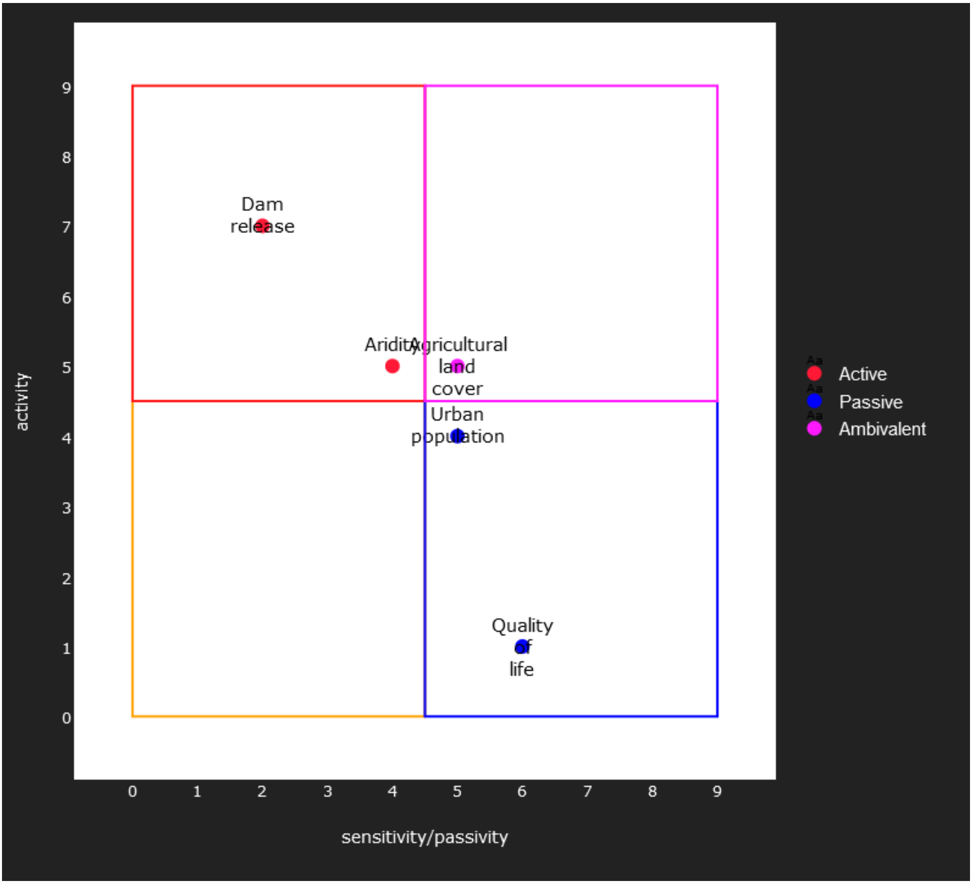

Figure 8: System grid, passivity (column sum), activity (row sum)

ASSESSING CONSISTENCY

The goal of this part is to describe how the software can be used to assess the consistency of the scenario. The consistent scenarios will be ranked rank according to their consistency scores. This will help to sort out inconsistent scenarios whose consideration is not meaningful.

When the user opens the software and clicks on "formative scenario analysis", a new window appears with two main sub-modules (scenarios visualization and consistency analysis).

The procedure starts (see Figure 9) by inserting the "Number of Impact Factors". The "Label for IFs level low " and for "… level high" have to be named. There is a common label for low and high for all impact factors.

The number of scenarios resulting from the number of impact factors and the levels of the impact factor is calculated and inserted by the program. After clicking on the module "consistency assessment and scenario ranking", an interactive window appears (see Figure 9) and the user proceeds as follows.

- Choose the label (numeric) for levels of impact factors such that the difference between them is 1 (recommendation: choose 0 and 1).
- Choose the number of impact factors (0-9). The number of scenarios N=2^{n_i}, with n_i the number of impact factors is calculated and inserted by the program.

The Demonstration Version (Demo-Version) includes only 9 impact factors. The full version will allow to include up to 20 impact factors.

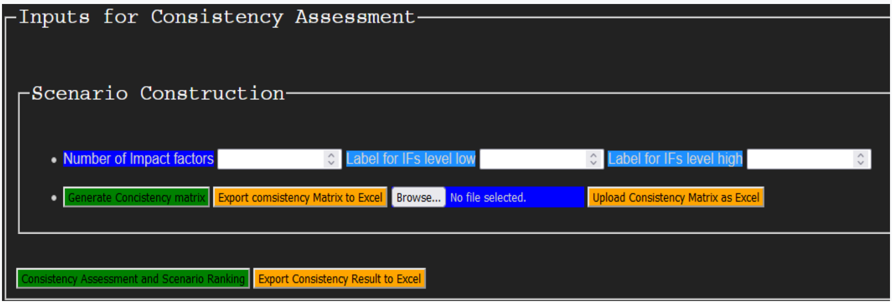

Figure 9: The interactive window for assessing consistency

Consistency values have to be assigned for all pairwise combinations of levels of impact factors.

The software assigns to each scenario a composite consistency value as the sum of pairwise consistency scores among the levels of impacts factors belonging to one scenario. The ratings of all possible levels of impact factors are included in the consistency matrix. The output of the consistency assessment, the consistency matrix" is thus a table (Figure 10).

After filling or uploading the consistency matrix, press the button consistency assessment and scenario ranking to obtain the result (see Figure 11). The user may choose to save the result as an excel file by pressing the appropriate button in the interactive window (see Figure 9).

-	Dam release (High)	Dam release (Low)	Agricultural Land Cover (High)	Agricultural Land Cover (Low)	Agricultural subsidies (High)	Agricultural subsidies (Low)
Dam release (High)	-	-	2	-1	2	2
Dam release (Low)	-	-	0	2	0	1
Agricultural Land Cover (High)	-	-	-	-	2	2
Agricultural Land Cover (Low)	-	-	-	-	1	0
Agricultural subsidies (High)	-	-	-	-	-	-
Agricultural	-	-	-	-	-	-

Figure 10: Consistency matrix filled with consistency measures

Scenarios	Dam release	Agricultural Land Cover	Agricultural subsidies	Consistency scores c(S.)
S1	1	1	0	6
S2	1	1	1	6
S3	0	0	0	3
S4	0	1	0	3
S5	0	0	1	3
S6	0	1	1	2
S7	1	0	1	2
S8	1	0	0	1

Figure 11: Result of consistency assessment

In Figure 11, 1 and 0 represent the levels "high" and "low" of impact factors, respectively. $S_i, i = 1, \ldots, 8$ is a scenario and $c(S_i), i = 1, \ldots, 8$ the consistency values assigned to each scenario.

METHOD 4: APPLYING THE SOFTWARE TOOL TO MCA

The goal of this part is to describe how can the software be used to assess MCA. The software takes as input the weights, scores, and thresholds of all criteria and assigns to each alternative the weighted sum using the composition rule. When the user opens the software with an appropriate browser and clicks on “multi-criteria assessment”, an interactive window appears (see Figure 12) and the user has to proceed as follows.

- Choose the number of alternatives (1-4) and the number of criteria (1-6)
- Generate the MCA matrix (see Figure 13) and fill it with weighting scores (0-10).
- After filling the MCA matrix, press the button “Result of MCA” and the following result shows up (see Figure 14)

The minimum criterion and the weights of all criteria for all scenarios are pre-defined by the study team and pre-inserted in the software. The user may choose to save the MCA matrix or the result as an excel file by pressing the appropriate button in the interactive window (see Figure 12)

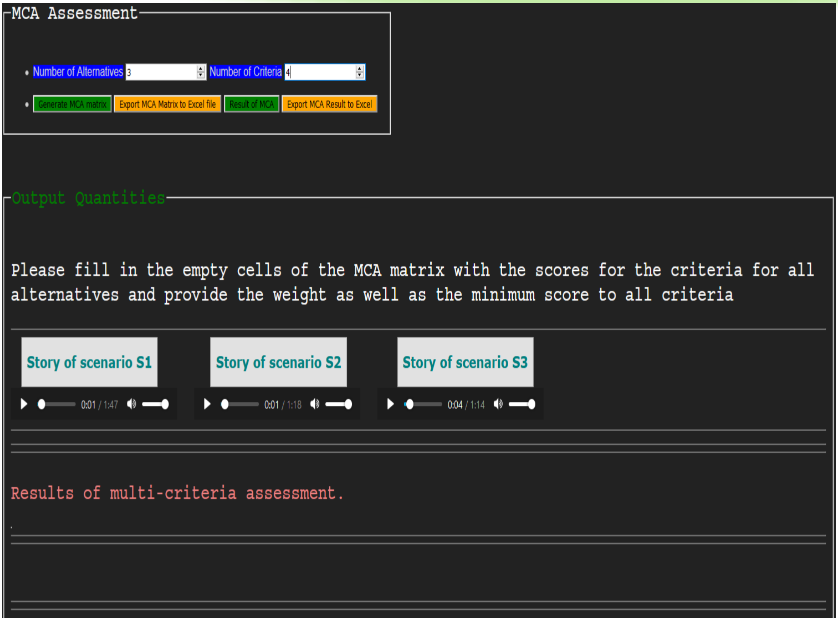

Figure 12: The interactive window for assessing MCA

Criteria/ Alternatives	Local environmental impact assessment (U1)	Global energy/ climate indicator (U2)	Local income assessment (U3)	Global economic performance (U4)
The good change of Drâa River Basin (S1)	9	6	9	1
A change to the worse of Drâa River Basin (S2)	5	7	8	9
The unexpected change of the Drâa River Basin (S3)	5	6	6	7

Figure 13: MCA matrix filled with weighting scores

Criteria/ Alternatives	Local environmental impact assessment (U1)	Global energy/ climate indicator (U2)	Local income assessment (U3)	Global economic performance (U4)	Weighted Sum Scores	Decision
The good change of Drâa River Basin (S1)	9	6	9	1	0.000	Unacceptable: Min(U4) > U14
A change to the worse of Drâa River Basin (S2)	5	7	8	9	7.267	acceptable
The unexpected change of the Drâa River Basin (S3)	5	6	6	7	6.033	acceptable
Weights	0.267	0.233	0.200	0.300	--	--
Thresholds/ Min(U)	2	2	3	2	--	--

```
Minimum score of the criterion for scenario to be acceptable: 2,2,3,2

scaled/relative weights: 0.267,0.233,0.200,0.300
Sum of the relative/scaled weights: 1

Weighted sum scores: 0.000,7.267,6.033
The following ranking can be derived, where the symbol '>' stands for 'better than'
S2 > S3 > S1
```

Figure 14: MCA result

METHOD 05: PRINCIPLES AND STRATEGIES OF SCENARIO SELECTION

K-MEANS AND HIERARCHICAL CLUSTER ANALYSIS OF SCENARIOS

Cluster analysis is a wide range of techniques for finding subgroups of observations in a given data set. It seeks to find relationships between observations without being driven by a response variable. Cluster analysis allows us to identify observations that are similar and possibly categorize them. K-means cluster analysis is the most commonly used unsupervised machine learning algorithm for partitioning a given data set into a set of *k* groups, where *k* represents the number of groups that can be pre-specified by the analyst. The algorithm classifies objects in multiple groups such that objects within the same cluster are as similar as possible, whereas objects from different groups (clusters) are as dissimilar as possible. In k-means clustering, each group is represented by its center (i.e, centroid) which corresponds to the mean of points assigned to the group.

Euclidean Distance Measures

To classify observations into groups requires some methods for computing the distance or the (dis)similarity between each pair of observations. The result of this computation is known as a dissimilarity or distance matrix. There are many methods to compute this distance measure. The choice of distance measures is a critical step in cluster analysis, it defines how the similarity of two elements (x, y) is computed and influences the shape of the clusters. The classical method for distance measures is *Euclidean*, which is defined as follow:

$$d(x,y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$$

Where, x and y are two vectors of length n.
The basic idea behind k-means cluster analysis consists of defining groups (clusters) so that the total intra-cluster variation (known as total within-cluster variation) is minimized. There are several k-means algorithms available. The standard algorithm is the Hartigan-Wong algorithm (1979), which defines the total variation within the cluster as the sum of the squared Euclidean distances between items and the corresponding centroid:

$$W(C_k) = \sum_{x_i \in C_k} (x_i - \mu_k)$$

where, x_i is a data point belonging to the cluster C_k and μ_k is the mean value of the points assigned to the cluster C_k.
Each observation x_i is assigned to a given cluster such that the sum of squares distance of the observation to their assigned cluster centers is μ_k minimized.

The *total within-cluster sum of square (wss)* measures the goodness of the clustering and the objective is to minimize it. We define the total within-cluster sum of square as follows:

$$T_{wss} = \sum_{k=1}^{K} W(C_k) = \sum_{k=1}^{K} \sum_{x_i \in C_k} (x_i - \mu_k)$$

Where K is the total number of clusters.

Summary of the k-mean algorithm

K-means algorithm can be summarized as follows:

1. Specify the number of clusters (K) to be created (by the analyst).
2. Select randomly k objects from the data set as the initial cluster centers.
3. Assigns each observation to their closest centroid, based on the Euclidean distance between the object and the centroid

4. For each of the k clusters update the cluster centroid by calculating the new mean values of all the data points in the cluster. The centroid of a *k*th cluster is a vector of length *m* containing the means of all variables for the observations in the kth cluster; *m* is the number of variables.
5. Iteratively minimize the total within sum of square. That is, iterate steps 3 and 4 until the cluster assignments stop changing or the maximum number of iterations is reached. By default, the R software uses 10 as the default value for the maximum number of iterations.

K-MEAN CLUSTERING WITH R SOFTWARE

DATA PREPARATION

To perform cluster analysis in R, generally, the data should be prepared as follows:

- Rows are observations (individuals) and columns are variables
- Any missing value in the data must be removed or estimated.
- The data must be standardized (i.e., scaled) to make variables comparable. We recall that standardization consists of transforming the variables such that they have mean zero and standard deviation one.

We will consider the demonstration case of Salidraa and use the first 30 most consistent scenarios getting from the consistency assessment, see figure 15.

Scenarios	Dammfreigabe	Landwirtschaftlich genutzte Flächen	Landwirtschaftliche Subventionen	Qualität des Lebens	Trockenheit	Versalzung	Ländliches Bevölkerungswachstum	Anzahl der Rohrbrunnen	Wachstum der städtischen Bevölkerung	Konsistenzwerte K(S.)
S1	0	0	0	0	1	1	0	0	1	65
S2	1	1	1	1	0	0	1	1	1	64
S3	0	0	0	0	1	1	0	1	1	63
S4	1	0	0	0	1	1	0	0	1	63
S5	1	1	1	1	0	0	1	1	0	62
S6	1	0	0	0	0	1	0	0	1	62
S7	0	0	0	0	1	1	0	0	0	61
S8	1	0	0	0	1	1	0	0	0	61
S9	0	0	0	0	0	1	0	0	1	61
S10	0	0	1	0	1	1	0	1	1	60
S11	1	1	1	1	0	1	1	1	1	60
S12	1	0	0	0	0	1	0	0	0	59
S13	1	0	0	0	0	0	0	0	1	59
S14	1	1	1	1	0	0	1	0	1	59
S15	1	0	0	1	0	1	0	0	1	58
S16	1	0	0	1	0	0	0	0	1	58
S17	0	1	1	0	1	1	1	1	1	58
S18	1	0	0	0	1	1	0	1	1	58
S19	0	1	1	1	0	0	1	1	1	58
S20	0	0	1	0	1	1	1	1	1	58
S21	1	1	1	1	0	0	1	0	0	58
S22	1	1	1	1	1	0	1	1	1	58
S23	0	0	0	0	1	1	0	1	0	58
S24	0	0	1	0	1	1	0	0	1	58
S25	1	1	1	0	0	0	1	1	1	58
S26	1	0	0	0	0	0	0	0	0	57
S27	1	0	0	0	1	0	0	0	1	57
S28	1	0	0	1	0	0	1	0	1	57
S29	1	1	1	1	1	1	1	1	1	57
S30	1	0	1	1	0	0	1	1	1	57
S31	1	0	0	1	1	1	0	0	1	57
S32	1	1	1	0	0	1	1	1	1	57

Figure 15: The 32 Most consistent Scenarios

To load the data in R we remove the first and the last column of the above table to obtain the following figure.

Dammfreigabe	Landwirtschaftlich_genutzte_Flächen	Landwirtschaftliche_Subventionen	Qualität_des_Lebens	Trockenheit	Versalzung	Ländliches_Bevölkerungswachstum	Anzahl_der_Rohrbrunnen	Wachstum_der_städtischen_Bevölkerung
0	0	0	0	1	1	0	0	1
1	1	1	1	0	0	1	1	1
0	0	0	0	1	1	0	1	1
1	0	0	0	1	1	0	0	1
1	1	1	1	0	0	1	1	0
1	0	0	0	0	1	0	0	1
0	0	0	0	1	1	0	0	0
1	0	0	0	1	1	0	0	0
0	0	0	0	0	1	0	0	1
0	0	1	0	1	1	0	1	1
1	1	1	1	0	1	1	1	1
1	0	0	0	0	1	0	0	0
1	0	0	0	0	0	0	0	1
1	1	1	1	0	0	1	0	1
1	0	0	1	0	1	0	0	1
1	0	0	1	0	0	0	0	1
0	1	1	0	1	1	1	1	1
1	0	0	0	1	1	0	1	1
0	1	1	1	0	0	1	1	1
0	0	1	0	1	1	1	1	1
1	1	1	1	0	0	1	0	0
1	1	1	1	1	0	1	1	1
0	0	0	0	1	1	0	1	0
0	0	1	0	1	1	0	0	1
1	1	1	0	0	0	1	1	1
1	0	0	0	0	0	0	0	0
1	0	0	0	1	0	0	0	1
1	0	0	1	0	0	1	0	1
1	1	1	1	1	1	1	1	1
1	0	1	1	0	0	1	1	1

Figure 16: Data preparation for cluster analysis in R

After loading the data in R, we scale (standardize) it in such a way that the variables which are columns have mean zero and standard deviation one. We standardize the data using the R function scale, we obtain the following figure:

Dammfreigabe	Landwirtschaftlich genutzteFlächen	Landwirtschaftliche Subventionen	Qualität des Lebens	Trockenheit	Versalzung	Ländliches Bevölkerungswachstum	Anzahl der Rohrbrunnen	Wachstum der städtischen Bevölkerung
-1.3904436	-0.6952218	-0.919692	-0.802773	1.051077	0.8597765	-0.8597765	-0.919692	0.5424047
0.6952218	1.3904436	1.051077	1.204159	-0.919692	-1.1243232	1.1243232	1.051077	0.5424047
-1.3904436	-0.6952218	-0.919692	-0.802773	1.051077	0.8597765	-0.8597765	1.051077	0.5424047
0.6952218	-0.6952218	-0.919692	-0.802773	1.051077	0.8597765	-0.8597765	-0.919692	0.5424047
0.6952218	1.3904436	1.051077	1.204159	-0.919692	-1.1243232	1.1243232	1.051077	-1.7821870
0.6952218	-0.6952218	-0.919692	-0.802773	-0.919692	0.8597765	-0.8597765	-0.919692	0.5424047
-1.3904436	-0.6952218	-0.919692	-0.802773	1.051077	0.8597765	-0.8597765	-0.919692	-1.7821870
0.6952218	-0.6952218	-0.919692	-0.802773	1.051077	0.8597765	-0.8597765	-0.919692	-1.7821870
-1.3904436	-0.6952218	-0.919692	-0.802773	-0.919692	0.8597765	-0.8597765	-0.919692	0.5424047
-1.3904436	-0.6952218	1.051077	-0.802773	1.051077	0.8597765	-0.8597765	1.051077	0.5424047
0.6952218	1.3904436	1.051077	1.204159	-0.919692	0.8597765	1.1243232	1.051077	0.5424047
0.6952218	-0.6952218	-0.919692	-0.802773	-0.919692	0.8597765	-0.8597765	-0.919692	-1.7821870
0.6952218	-0.6952218	-0.919692	-0.802773	-0.919692	-1.1243232	-0.8597765	-0.919692	0.5424047
0.6952218	1.3904436	1.051077	1.204159	-0.919692	-1.1243232	1.1243232	-0.919692	0.5424047
0.6952218	-0.6952218	-0.919692	1.204159	-0.919692	0.8597765	-0.8597765	-0.919692	0.5424047
0.6952218	-0.6952218	-0.919692	1.204159	-0.919692	-1.1243232	-0.8597765	-0.919692	0.5424047
-1.3904436	1.3904436	1.051077	-0.802773	1.051077	0.8597765	1.1243232	1.051077	0.5424047
0.6952218	-0.6952218	-0.919692	-0.802773	1.051077	0.8597765	-0.8597765	1.051077	0.5424047
-1.3904436	1.3904436	1.051077	1.204159	-0.919692	-1.1243232	1.1243232	1.051077	0.5424047
-1.3904436	-0.6952218	1.051077	-0.802773	1.051077	0.8597765	1.1243232	1.051077	0.5424047
0.6952218	1.3904436	1.051077	1.204159	-0.919692	-1.1243232	1.1243232	-0.919692	-1.7821870
0.6952218	1.3904436	1.051077	1.204159	1.051077	-1.1243232	1.1243232	1.051077	0.5424047
-1.3904436	-0.6952218	-0.919692	-0.802773	1.051077	0.8597765	-0.8597765	1.051077	-1.7821870
-1.3904436	-0.6952218	1.051077	-0.802773	1.051077	0.8597765	-0.8597765	-0.919692	0.5424047
0.6952218	1.3904436	1.051077	-0.802773	-0.919692	-1.1243232	1.1243232	1.051077	0.5424047
0.6952218	-0.6952218	-0.919692	-0.802773	-0.919692	-1.1243232	-0.8597765	-0.919692	-1.7821870
0.6952218	-0.6952218	-0.919692	-0.802773	1.051077	-1.1243232	-0.8597765	-0.919692	0.5424047
0.6952218	-0.6952218	-0.919692	1.204159	-0.919692	-1.1243232	1.1243232	-0.919692	0.5424047
0.6952218	1.3904436	1.051077	1.204159	1.051077	0.8597765	1.1243232	1.051077	0.5424047
0.6952218	-0.6952218	1.051077	1.204159	-0.919692	-1.1243232	1.1243232	1.051077	0.5424047

Figure 17: Standardize data

DISTANCE MATRIX

After scaling the data, we compute the Euclidean distance of each pair of observations using the R function get_dist from the factoextra R package to obtain the so-called distance matrix. Within R it is possible to visualize the distance matrix using the functions fviz_dist from the factoextra R package. This starts to illustrate which states have large dissimilarities (red) versus those that appear to be fairly similar (teal). Considering our example we obtain the following figure:

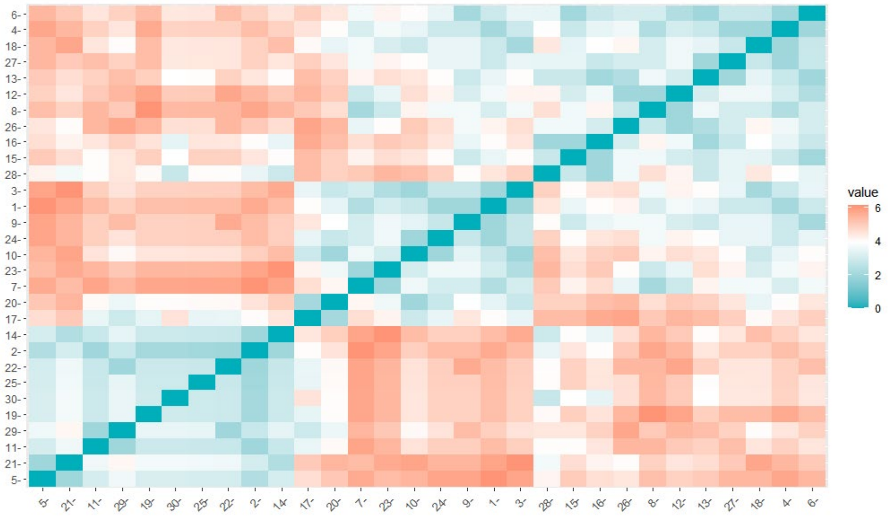

Figure 18: Distance matrix visualization

COMPUTE K-MEANS CLUSTER

In R the K-means can be computed using the R function kmeans. This will group the data into k clusters (centers=k). This function also has an nstart option that attempts multiple initial configurations and reports on the best one. For example, adding nstart = 25 will generate 25 initial configurations. This approach is often recommended.

The output of kmeans is a list containing the following information.

- cluster: A vector of integers (from 1:k) indicating the cluster to which each point is allocated.
- totss: centers: A matrix of cluster centers.
- The total sum of squares.
- withinss: Vector of within-cluster sum of squares, one component per cluster.
- tot.withinss: Total within-cluster sum of squares, i.e. sum(withinss).
- betweenss: The between-cluster sum of squares, i.e. totss-tot.withinss.

- size: The number of points in each cluster.

If we consider our example of salidraa case, the kmeans function gives the results depicted in figure 19. We observe that our groupings resulted in 3 cluster sizes of 11, 10, and 9. We also see the cluster centers (means) for the three groups across the 9 variables (Dammfreigabe, Landwirtschaftlich genutzte Flächen, Landwirtschaftliche Subventionen, Qualität des Lebens, Trockenheit, Versalzung, Ländliches Bevölkerungswachstum, Anzahl der Rohrbrunnen, Wachstum der städtischen Bevölkerung). We also get the cluster assignment for each observation (i.e. scenarios 1, 3, 7, 10, are assigned to cluster 3, scenarios 2, 5, 11, 14 are assigned to cluster 2, scenarios 4, 6, 8, 9 are assigned to cluster 1, etc.).

```
List of 9
 $ cluster     : int [1:30] 3 2 3 1 2 1 3 1 1 3 ...
 $ centers     : num [1:3, 1:9] 0.506 0.487 -1.159 -0.695 1.182 ...
  ..- attr(*, "dimnames")=List of 2
  .. ..$ : chr [1:3] "1" "2" "3"
  .. ..$ : chr [1:9] "Dammfreigabe" "Landwirtschaftlich_genutzte_Flächen" "Landwirtschaftliche_Subventionen" "Qualität_des_Lebens" ...
 $ totss       : num 261
 $ withinss    : num [1:3] 47.3 38.8 38.7
 $ tot.withinss: num 125
 $ betweenss   : num 136
 $ size        : int [1:3] 11 10 9
 $ iter        : int 2
 $ ifault      : int 0
 - attr(*, "class")= chr "kmeans"

K-means clustering with 3 clusters of sizes 11, 10, 9

Cluster means:
  Dammfreigabe  Landwirtschaftlich   Landwirtschaftliche  Qualität des                Versalzung   Ländliches                Anzahl der    Wachstum der
                genutzte Flächen     Subventionen         Lebens        Trockenheit                Bevölkerungswachstum      Rohrbrunnen   städtischen Bevölkerung
1    0.5056158     -0.6952218         -0.91969198         -0.2554278   -0.3822097   -0.04208696   -0.6794038                -0.9196920    -0.09157483
2    0.4866553      1.1818770          1.05107655          1.0034662   -0.5255383   -0.72750322    1.1243232                 0.6569228     0.07748639
3   -1.1587030     -0.4634812         -0.04379486         -0.8027730    1.0510765    0.85977653   -0.4188655                 0.3941537     0.02582880

Clustering vector:
 [1] 3 2 3 1 2 1 3 1 1 3 2 1 1 2 1 1 3 3 2 3 2 2 3 3 2 1 1 1 2 2

Within cluster sum of squares by cluster:
[1] 47.32150 38.82818 38.66162
 (between_SS / total_SS =  52.2 %)

Available components:

[1] "cluster"      "centers"      "totss"        "withinss"     "tot.withinss" "betweenss"    "size"         "iter"         "ifault"
```

Figure 19: Output of the k-means R function

CLUSTER VISUALIZATION

We can also visualize the results using the R function fviz_cluster. If there are more than two dimensions (variables) the R function fviz_cluster will perform principal component analysis (PCA) and plot the data points according to the first two principal components that explain the majority of the variance. The cluster plot of the first 30 most consistent scenarios of the Salidraa case is depicted in figure 20.

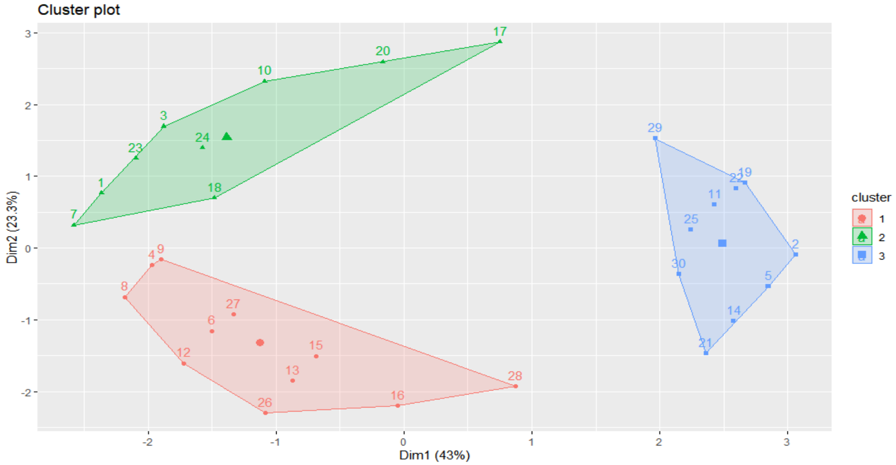

Figure 20: Cluster plot of 30 scenarios

Since the number of clusters (k) must be set before we start the algorithm, it is often advantageous to use several different values of k and examine the differences in the results. We can execute the same process for 2, 4, and 5 clusters, and the results are shown in figure 21:

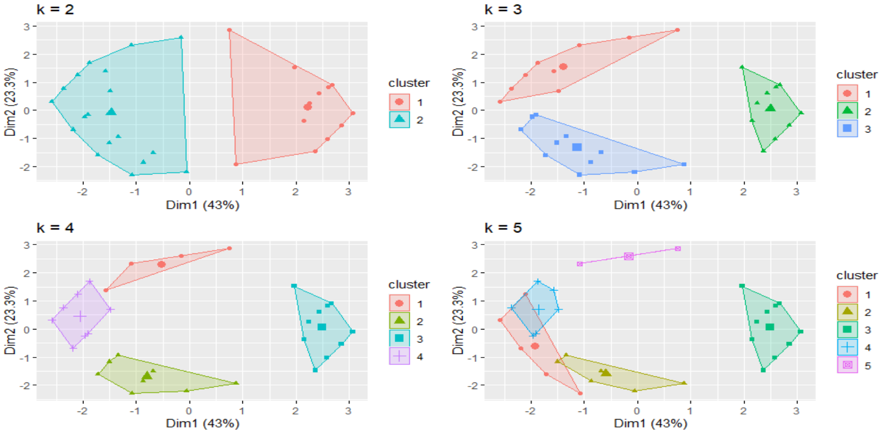

Figure 21: Comparison of Cluster plots for k=2, 3, 4, 5

Although this visual assessment tells us where true boundaries occur (or do not occur such as clusters 1 and 3 in the k = 5 graph) between clusters, it does not tell us what the optimal number of clusters is.

COMPUTING THE OPTIMAL NUMBER OF CLUSTERS: GAP STATISTIC METHOD

We refer the method to R. Tibshirani, G. Walther, and T. Hastie (Standford University, 2001). The method can be applied to any clustering method (i.e. K-means clustering, hierarchical clustering). The gap statistic compares the total intracluster variation for different values of k with their expected values under the null reference distribution of the data (i.e. a distribution with no obvious clustering). The reference dataset is generated using Monte Carlo simulations of the sampling process. That is, for each variable (x_i) in the data set we compute its range $min(x_i)$, max (x_i) and generate values for the n points uniformly from the interval min to max. The gap statistic can be computed in R using the function clusGap to visualize the result one can use the function fviz_gap_stat. The result of the gap statistic applied to our data gives the result depicted in figure 22:

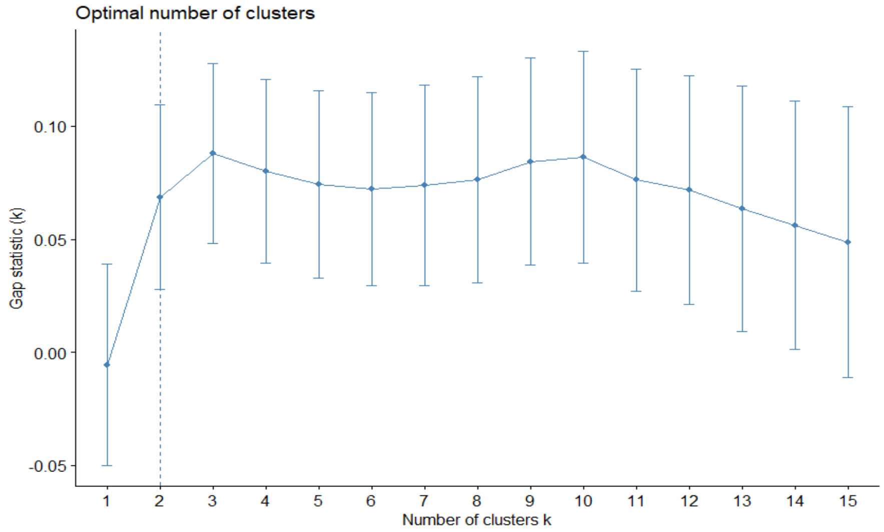

Figure 22: Optimal number of clusters

DENDROGRAMS

In hierarchical clustering, the objects are categorized into a hierarchy similar to a tree-like diagram which is called a dendrogram. The distance of split or merge (called height) is shown on the y-axis of the dendrogram, see figure 23 below.

In the first block in the figure below, first, 2 and 14 are combined into one cluster, called cluster 1; 11 and 29 are combined into one cluster, called cluster 2; 5 and 21 are combined into one cluster, called cluster 3 since they were closest in distance. Then 22 was merged into the same cluster 1, followed by 25, 19, and 30, resulting in one large cluster, the new cluster 1. Next, cluster 2 is merged with the new cluster 1 to form a large cluster, the new cluster 2. Next, the new cluster 2 is merged with cluster 3 to form a single cluster, the new cluster 3. Using the same process, blocks 2 and 3 are formed and then merged into one large cluster, called cluster 4. Finally, the new cluster 3 is merged with cluster 4 to form a single cluster, and this is where the clustering process ends.

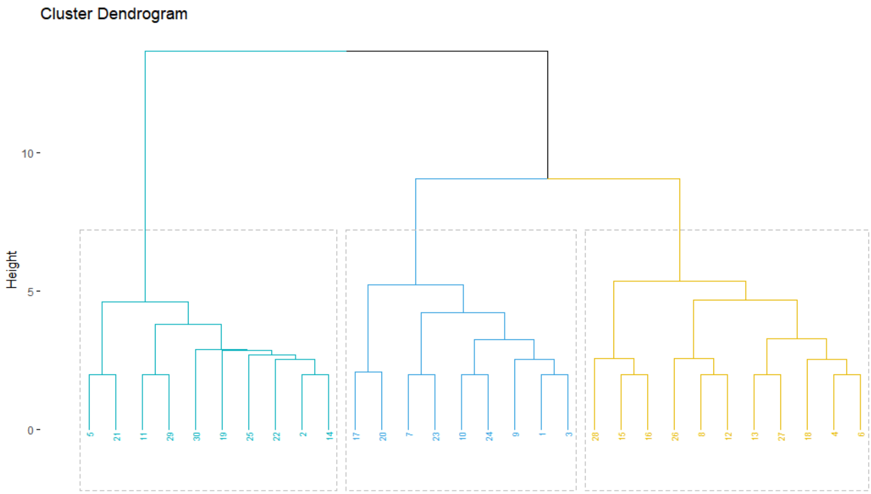

Figure 23: Dendrogram of the first 30 most consistent scenarios

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