EU-CIRCLE

A pan-European framework for strengthening Critical Infrastructure resilience to climate change

D4.7 COST-EFFECTIVENESS ANALYSIS

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Statement

This document contains a collection of different assessment approaches for the comparison of several adaptation options relating to improvement of resilience of CI. The objective is to find an adaptation measurement which achieves a main purpose by consideration of costs and benefits.

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Abbreviations List	
Term	Description
AHP	Analytic Hierarchy Process
BaU	Business as Usual
CAPEX	Capital Expenditures
CBA	Cost Benefit Analysis
CEA	Cost Effectiveness Analysis
CI	Critical Infrastructure
DIIM	Dynamic Inoperability Input Output Model
DSER	Direct Static Economic Resilience
IIM	Inoperability Input Output Model
MA	Macroeconomic Analysis
MADM	Multi-Attribute Decision Making
MCDA	Multi-Criteria Decision Analysis
MCA	Multi-Criteria Analysis
MODM	Multi-Objective Decision Making
NPV	Net Present Value
NSB	Net Social Benefit
OPEX	Operational Expenditures
PV	Present Value
SAM	Social Accounting Matrix
TSER	Total static economic resilience
VSL	Value of a statistical life

Executive Summary

The objective of this deliverable is to investigate different adaptation scenarios. These adaptation measures aim to enhance the resilience capacities of a critical infrastructure regarding extreme weather events as a result of climate change. For the investigation the purpose is to develop an assessment procedure for comparing different adaptation options. Therefore four approaches (Cost Benefit Analysis - CBA, Cost-Effectiveness Analysis - CEA, Macroeconomic Analysis - MA & Multi-Criteria Analysis - MCA) will be investigated regarding their applicability within EU-CIRCLE.

The main objective is to select one of the above mentioned methods or develop an own EU-Circle assessment method which is a kind of compilation of the examined assessment approaches. Irrespective which of the aforementioned approaches will be chosen this provides the coherent basis for the comparison of different resilience policies and adaptation measures.

The Task of Cost- Effectiveness Analysis is Part of the adaptation framework which will be elaborate in T4.4 EU-CIRCLE Framework for CI adaptation to climate change and D4.6 (CI adaptation to climate hazard model). After the specific adaptation options were defined, in a second step the Cost-Effectiveness Analysis will be conducted based on the output of the risk and resilience assessment (D3.5 and D4.3). The Output of D4.7 will provide recommendations for the conclusive Adaptation Decision Support Module in EU-CIRCLE. Figure 1 depicts the integration of Cost-Effectiveness Analysis into the adaptation framework.

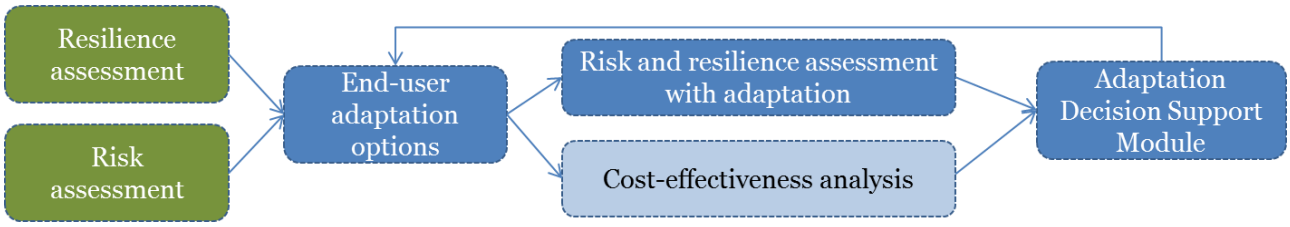


Figure 1: schematic representation of the adaptation framework

Contents

1 Introduction

The following deliverable report aims on different economic assessment measures which have the objective to evaluate different adaptation options. Within EU-CIRCLE these adaptation options will be defined in the case studies. Based on these options this report investigates four different assessment tools for prioritization and selection of the most appropriate option. The four main measures are presented by the Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA), Macroeconomic Analysis (MA) and Multi-Criteria Analysis (MCA). In order to find the appropriate assessment measure for a specific adaptation option, it is necessary to estimate these methods. For this estimation it is suitable to define advantages and disadvantages of these tools regarding to mathematic conditions and the procedure as a whole.

The scope of this economic assessment refers to the influence of climate change and the related hazards on critical infrastructure (CI). The aim is to enhance the resilience of CI regarding the exposure to extreme weather events like floods, forest fires etc. Within EU-Circle resilience is described by the ability of a CI system to prevent, withstand, recover and adapt from the effects of climate hazards and climate change from the holistic point of view, including socio-economic aspects of resilience as well. If the resilience of a CI is unable to deal with the consequences of climate change it is necessary to develop certain adaptation options which increase the resilience of the CI.

To assess and select different options it is necessary to define input parameters –mostly included in WP3 and especially in the Holistic Risk Assessment Propagation Model (Task 3.5).

Table 1: Categories of impacts

Categories of impacts	
Direct impacts	Indirect Impacts
Damages to CI assets	Impact on societal groups
CI performance	Casualties
Safety indices	Economic impacts
Casualties	
Economic and financial perspectives	
Environmental Losses	
Ci reputation	
Proxy (for not climate caused impacts)	

The analysed impacts are the foundation for the execution of the economic appraisal in Task 4.5 – Cost-Effectiveness Analysis. This means it includes direct impacts, indirect impacts as well as socio-economic impacts. All in all D4.7 is a conclusion after the process of risk respectively resilience assessment and provide the recommendations for the final Adaptation Decision support module which is also part of the Adaptation model.

The following chapters investigate the different adaptation assessment tools and have the objective to find a consolidated and common language. In this case the purpose is to find a specific assessment approach which is appropriate to evaluate the applicable for the different case studies.

2 Cost-Benefit Analysis (CBA)

2.1 Cost-Benefit Analysis in general

The Cost-Benefit Analysis (CBA) is an analytical assessment procedure for the evaluation of economic advantages and disadvantages regarding an investment decision. Such an investment decision could be based on policies, projects, regulations, programs or other government interventions. The term project or policy will be used interchangeably throughout this section about the CBA and comprises all kind of investment decisions. The CBA try to consider all effects (costs and benefits) to a society as o whole. This means that social benefits (B) as well as social costs (C) are considered. The overall value of a project can be measured by the *net social benefit* (NSB) which is defined by the below mentioned equation. At this the CBA appraise costs and benefits in order to evaluate the welfare change at all [7].

$$NSB = B - C$$

In contrast to other assessment procedures (e.g. cost utility analysis or Cost-Effectiveness Analysis) the Cost-Benefit Analysis considers all positive and negative effects and transforms them into monetary units. For the evaluation of cost- and benefit components which arise in non-monetary units there are two different opportunities for transformation in monetary units. On the one hand there are direct approaches and on the other hand indirect approaches.

Infrastructure projects mostly aimed to operate on a large time horizon. Therefore all costs and benefits shall be comparable to the same date. The Net Present Value (NPV) ensures this condition. All cash flows along the period under observation will discounted to the respective date – date of decision making. The below mentioned formula depicts calculating the NPV:

$$NPV = \sum_{t=0}^{T} (B_t - C_t) * (1+s)^{-t}$$

$$B_t = benefits\ in\ period\ t$$
$$C_t = costs\ in\ period\ t$$
$$s = rate\ of\ interest$$

Minimum requirement for positive decision regarding a project realisation:

$$\sum_{t=0}^{T} B_t\,(1+s)^{-t} - \sum_{t=0}^{T} C_t\,(1+s)^{-t} > 0$$

or:

$$\frac{\sum_{t=0}^{T} B_t\,(1+s)^{-t}}{\sum_{t=0}^{T} C_t\,(1+s)^{-t}} > 1$$

If there is more than one project alternative which fulfil the condition of the formulas above and there is no budget restriction all alternatives are worthy to be realized. Since most projects have such budget restrictions, the alternative which complies this restriction and which has the highest Net Present Value have to be chosen [22].

Respectively to the date of evaluation there are two major types of CBA. The ex ante CBA is made while a project is under consideration before it is implemented. An ex post CBA is executed after a specific project implemented. Beside these two major types there are also in medias res analysis and a kind of comparison between ex ante and ex post CBA. Within the scope of EU-CIRCLE the aim is to identify adaptation option and choose the policy which pursues the interests of stakeholders in the best way. In this case mostly ex ante assessments are a possibility. So the ex ante Cost-Benefit Analysis is part of the following description.

2.2 Process of the Cost-Benefit Analysis in EU-CIRCLE

For the approach of a Cost-Benefit Analysis within EU-CIRCLE the following nine steps below according to Boardman et al. 2006 can be applied. The following description fits these steps with the requirements of EU-CIRCLE:

1. Specify the set of alternative projects
2. Decide whose benefits and costs count (standing)
3. Catalogue the impacts and select measurement indicators
4. Predict the impacts quantitatively over several years of the period under observation
5. Monetize (attach monetary values to) all impacts
6. Discount benefits and costs to obtain present value
7. Compute the net present value of each alternative
8. Perform sensitivity analysis
9. Make a recommendation

Placed in front of these steps, the objectives of a project have to be defined by the decision maker. Without an objective the characteristics of the alternatives cannot specified because there are no targets to achieve for the alternatives [30].

Specify the set of alternative projects

In the first step the alternatives have to be defined (A_i, i=1, 2, 3, .., n). These defined alternatives build the set of alternatives. Each of this will be compared with a hypothetical project which is called the *counter-factual*. Usually, the status quo is this counter-factual. In the status quo there are no changes in the project which means no adaptation is done. In the further steps the potential project benefits were compared with the benefits under the status quo which is used as a benchmark. Thus, the status quo operates as a reference alternative (A_0).

Decide whose benefits and costs count (standing)

This step refers to the scope of investigation. The question remains if the CBA should include global, regional or municipal costs and benefits. This is a matter on which decision makers have to answer because costs and benefits certainly diverge dependent on a global, regional or municipal perspective.

Catalogue the impacts and select measurement indicators

In this step a list of physical impacts is required. These impacts are expected from Task 3.5 Holistic Risk assessment Propagation Model. According to D1.5 – Report On Detailed Methodological Framework (section 3.3.2) we can outline the progress from hazard assessment across the damage assessment to the impacts assessment. Crucial for the execution of a Cost-Benefit Analysis are the estimation of the impacts. At the end of the damage assessment the damages will be aggregated to determine the impact. These impacts can divided into direct and indirect Impacts. Table 2 collects the main impact categories that will be considered.

Table 2: Categories of impacts

Categories of impacts	
Direct impacts	Indirect Impacts
Damages to CI assets	Impact on societal groups
CI performance	Casualties
Safety indices	Economic impacts
Casualties	
Economic and financial perspectives	
Environmental Losses	
Ci reputation	
Proxy (for not climate caused impacts)	

As a part of the previous impact assessment these categories of impacts can be matched with specific weights which will be assigned by the users and their respective preferences. Additionally, was added a proxy for not climate related impacts (e.g. time saving on a new traffic road). The final risk assessment will be computed by the product of calculated impacts and the likelihood of an Extreme Event which is described in section 3.2 of D1.5 and conducted in work package 2.

Additionally to the output from the impacts assessment we have to define other input data which is essential for the execution of a Cost-Benefit Analysis. Table 3 depicts a summary of input data which is divided in costs and benefits.

Table 3: Costs and benefits within a Cost-Benefit Analysis in EU-CIRCLE

Costs and benefits within a Cost-Benefit Analysis in EU-CIRCLE	
Cost components	Benefit components
Capital expenditures (CAPEX) – Implementation of an adaptation option	Reduced impacts (Impacts of A_0 minus impacts of A_i)
Operational expenditures (OPEX) – Implementation of an adaptation option	Residual value at the end of the period under observation

Capital expenditures (CAPEX) and Operational expenditures (OPEX) are case-specific and have to be estimate externally. CAPEX refer to the investment costs and OPEX to cost of maintenance, repair cost, operational costs etc. Also the value of the adaptation measure at the end of the period under observation, called the residual value, have to be calculate externally. Among others this residual value results dependent on depreciation. The aforementioned inputs are dependent on the adaptation option and the end user preferences. Sources for this estimation could be evaluated during the communication with stakeholders.

The reduced damage costs (reduced impacts) can be considered as a result of the EU-CIRCLE Holistic Risk Assessment Framework. This means in any case the assessment of the reference case (status quo) is necessary. All categories of Table 2 can build a several cost/benefit component. Simplified, the reduced overall impacts treated as benefits and can be computed by:

$$\sum Impacts\ A_0 - \sum Impacts\ A_i$$

It is assumed that the impacts of A_i are less than the impacts of A_0. Otherwise the adaptation measure would not take into account because A_i wouldn't improve the resilience of the status quo.

Predict the impacts quantitatively over the life of the project

As it is mentioned above within EU-CIRCLE this quantification is a result (output) of the Holistic Risk Assessment Framework and will be used as input for the Cost-Benefit Analysis.

Impacts should be quantified where possible. When there are impacts for which it is impossible to quantify them, the impact should at least be mentioned. It is suggested to collect them in a list so that they can be considered in context with the computed CBA. For example if there are environmental impacts which can't be quantified, these should be mentioned as an additional remark, although it cannot be measured in a monetary unit. A common approach for non-quantified impacts is to calculate how large they would need to disprove the CBA results. So the analyst can assess how likely or unlikely it is that the collected non-quantified impacts reach this critical value [32].

Monetize (attach monetary values to) all impacts

To monetize values refers to the procedure to add a monetary value in a specific currency to each category of impact. This means that each kind of impact in Table 2 has to attach a value in a specific currency. Some inputs will have stable and clear defined prices, others may not be traded in markets at all. This is necessitating other methods of evaluations [32]. The approach of shadow prices could be a helpful for the assignment of cost and benefits.

Nonmarket costs and benefits can be assessed through direct and indirect approaches. Much discussed impacts are casualties in relation to the value of life. To assess a value on a human life is one of the most controversial issues in a Cost-Benefit Analysis. There are many different analyses and researches which try to elaborate the value of a statistical life (VSL). Based on three different studies Boardman et al. 2006 suggest to estimate the value of a statistical life with 2.0 million $ in the United States and evaluate them in the sensitivity analysis with $2 million and $6 million.

The ethical question remains if a human life should assessed by a monetary value. Another approach is to list the impact of casualties in a separate as it is mentioned above. At the end the analyst can calculate how large the collected impacts of this separate list could be before they reverse the result of the CBA. Further difficulties regarding this monetarization will be investigated in Chapter 6 of this Deliverable.

Discount benefits and costs to obtain present value

For the assessment of costs and benefits of an infrastructure project it is needed to evaluate a long term of period to observe. The period under observation can be taken a several years. For this it is necessary to discount future costs and benefits to their present value (PV). The discounting is due to most people's preference to consume now rather than later. Generally it is recognized that costs and benefits which arises in the future are of less value than impacts today. This is also linked to give-up of resources which means there is an opportunity cost. A cost or a benefit can be discounted by the below mentioned equations. C_t and B_t are related to the cost and benefits in the year t and s is the social discount rate. For projects which don't have an impact beyond 50 years the social discount rate (inflation-adjusted) is recommended to set at 3.5 %. If a project is intergenerational (> 50 years) then the recommendation is dependent on several factors like the circumstance of possible crowding out private investments. These circumstances have to evaluate in the communication with stakeholders.

$$PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+s)^t}$$

$$PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$$

Compute the net present value of each alternative

As a result of the above mentioned equation the net present value can be computed by:

$$NPV = PV(B) - PV(C)$$

This leads to the general equations of section 2.1 for calculating the net present value. So the decision regarding an adaptation option and its status quo is very simple. We can adopt A_i if its NPV > 0. This means that its benefits exceed its costs.

If there are more than one adaptation options, the option with the largest NPV has to be selected. This assumes that there is at least one adaptation option with a positive value of NPV. If none of the options have a positive NPV, then no option superior the status quo which should remain in place.

Perform sensitivity analysis

As it was mentioned previously, there is a degree of uncertainty. This pertains for example the predicted impacts, the assumed social discount rate and the following monetary valuation. The aim of a sensitivity analysis is to deal with these uncertainties. It is proposed to vary the input parameters by carefully thought-out scenarios than by vague varying of assumptions. A common approach is to calculate a worst-case, best-case and intermediate scenario. So the decision makers get an idea regarding the degree of uncertainty.

Make a recommendation

First it has to be said that a Cost-benefit Analysis make recommendation, not decisions. Indeed, a CBA can be used as an input for the political decision making process. In general the adaptation option with the largest NPV should recommend. Beside the net present value there are two other criteria to provide the decision making process. These are the internal rate of return and the benefit-cost ratio. However, the NPV is the recommended decision criterion.

3 Cost-effectiveness analysis (CEA)

3.1 Cost-effectiveness analysis in general

Cost-effectiveness Analysis (CEA) is an economic assessment methodology and is used for choosing the less cost-optimum effectiveness among alternative decisions/policies. CEA, in general, can be selected when costs are well or partially defined in monetary terms and benefits can be qualitatively defined as effects – in physical units, non-monetary terms.

Within CEA cost and effectiveness assessment units of measurement:

- costs are evaluated in monetary units
- benefits (effectiveness) evaluated in their respective physical, qualitative units

CEA's objective is the calculation of a cost-effectiveness ratio for each alternative (measure, policy, decision etc.) The most preferable alternative is the one that presents the lowest ratio-value and highest effectiveness. The main question that CEA is reaching is the utilization when **minimization of cost** is favoured or in other words which alternative reaches the objective with lowest costs.

Concerning the Climate Change Adaptation Options, CEA is *"applied CEA is applied in assessing adaptation options in areas where adaptation benefits are difficult to express in monetary terms, including human health, freshwater systems, extreme weather events, and biodiversity and ecosystem services; but where costs can be quantified. For example, given the necessity for water, the aim of an assessment is not to find alternative adaptation options that might yield higher adaptation benefits, but to find those options that ensure sustainable water quality and quantity for vulnerable communities"* (ASSESSING THE COSTS AND BENEFITS OF ADAPTATION OPTIONS AN OVERVIEW OF APPROACHES, 2009)

3.2 Steps of the cost effectiveness analysis in EU-CIRCLE

1. Define and analyse the main objective and Identification of Alternative Options of Adaptation

The first and more important stage of CEA is the well-defined adaptation objective which has to be achieved by a measure/policy. For the cases that alternative options are available, the objectives must be described as complete, consistent and measurable as possible. Additional conditions need to be defined and fulfilled to achieve the main objective and the alternative options. All options should also be determined quantitatively and qualitatively (i.e. operational and construction cost for an electricity CI and amount of services in respect units – KWh).

2. Establish a reference point

A reference point or a baseline should be established in order a comparable analysis to be achieved. In this way, a "business as usual" (BaU) scenario is needed to define whether the target is achievable and at what extent. The baseline scenario should also be determined quantitatively and qualitatively (i.e. today's operational and construction cost for a transport CI and amount of services in respect units – number of served vehicles).

3. Costing of alternatives options

All costs regarding the alternative options should be aggregated and quantified including direct and indirect cost as well as the costs referring to the whole life-cycle of any option. In order the measurement to be credible, all costs in monetary terms should be discounted to their present value using a suitable discounting rate. For example, the adaptation of a transport CI against a flood should include the repair cost, the cost of maintenance, the operational cost etc. over time in present values.

4. Setting out the effectiveness

The effectiveness of any adaptation option should be determined with regards to the BaU scenario. The effectiveness is measured usually only in qualitative units. For example, if the adaptation option of step 3 is adopted, the rescue of lives or the avoidance of accidents, the saving of person hours, the served population etc. should be recorded.

More particularly:

The effectiveness should be measurable and relevant and separated in two steps:

- Development and determination of benchmarks (BaU) regarding the level of target achievement
- Measuring of the effectiveness for each alternative based on different level of scalability:
  - a) nominal scale – only incidence
  - b) ordinal scale – incidence and order
  - c) cardinal scale consisting of
    - c1) interval scale – incidence, order, distance
    - c2) relation scale – incidence, order, distance, zero point

5. Homogenization of other parameters

- Costs will be arising may be temporary differentiated; to make alternatives comparable to each other all costs and effectivities are related to a specific point of time.
- Consideration of risks and uncertainty:

  Due to partial completeness of information costs and effectiveness as appropriate may have different expected results. Thus, a differentiation between risks should be made

  (1) Decision on objective risk – statistical probabilities may be assigned

  (2) Decision on subjective risk – only subjective probabilities may be assigned (there might be intense precipitation which causes floods, but probabilities for occurrence cannot be defined)
- In case of decision at uncertainty – where no statistical nor subjective probabilities can be applied a sensitivity analysis is often the preferable option.

6. Decision on cost-effectiveness options

With regards to the available data or certain decisions should be made, or the available amount of adaptation options a few comparative methods can be applied:

<u>One Adaptation Option - Overall cost-effectiveness:</u>

Cost-effectiveness can be compared overall: An overall cost-effective analysis simply compares the cost per unit of effectiveness for each adaptation option (e.g. € per 1 KWh). This method can be applied for those cases that except for BaU there is only one adaptation option.

<u>Two Adaptation Options - Incremental cost effectiveness:</u>

An incremental cost effectiveness ratio is expressed by:

$$\frac{\text{Cost Option A} - \text{Cost Option B}}{\text{Effectiveness of A} - \text{Effectiveness of B}}$$

Where A is the more effective policy measure and B is the second most effective.

This method is used when except for BaU there are two adaptation options applicable.

More Adaptation Options:

When the adaptation options are more than two, the construction of a **cost-effectiveness-matrix** should be preferred in order to be comparable.

Cost-effectiveness Matrix:

Table 4: Example for cost-effectiveness-matrix

alternative	costs	degree of achievement - objective 1	degree of achievement - objective 2	degree of achievement - objective 2
A	C1	W11	W21	W31
B	C2	W12	W22	W32
C	C3	W13	W23	W33

Cost-effectiveness-diagram:

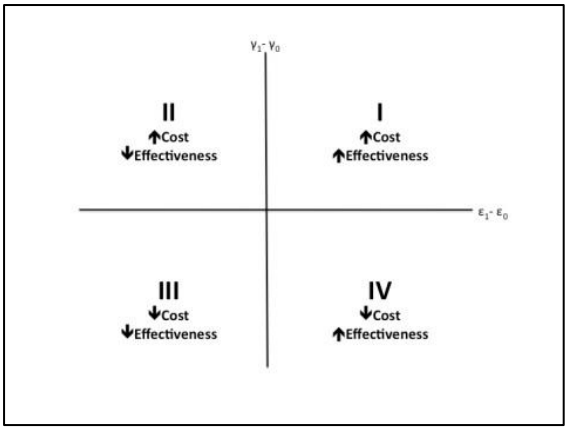


Figure 2: Cost-effectivness-diagram (https://commons.wikimedia.org/wiki/File:ICER_Bayesian_Tetralogical_Matrix.jpg)

4 Macroeconomic Analysis (MA)

4.1 The Input-Output Model in brief

The model depicts inter-industry relationships within an economy, showing how output from one industrial sector may become an input to another industrial sector. In the inter-industry matrix, column entries typically represent inputs to an industrial sector, while row entries represent outputs from a given sector. This format therefore shows how dependent each sector is on every other sector, both as a customer of outputs from other sectors and as a supplier of inputs. Each column of the input–output matrix shows the monetary value of inputs to each sector and each row represents the value of each sector's outputs[1].

The Table 5 as presented below depicts a typical Input-Output Table where the rows describe the distribution of a producer's output throughout the economy. The columns describe the composition of inputs required by a particular industry to produce its output. The additional columns, labelled Final Demand, record the sales by each sector to final markets for their production, such as personal consumption purchases and sales to the federal government. For example, electricity is sold to businesses in other sectors as an input to production (an interindustry transaction) and also to residential consumers (a final-demand sale). The additional rows, labeled Value Added, account for the other (non-industrial) inputs to production, such as labor, depreciation of capital, indirect business taxes, and imports (Miller and Blair, 2013).

Table 5: Input–Output Transactions Table, Source: (Miller and Blair, 2013)

		PRODUCERS AS CONSUMERS								FINAL DEMAND			
		Agric.	Mining	Const.	Manuf.	Trade	Transp.	Services	Other	Personal Consumption Expenditures	Gross Private Domestic Investment	Govt. Purchases of Goods & Services	Net Exports of Goods & Services
PRODUCERS	Agriculture												
	Mining												
	Construction												
	Manufacturing												
	Trade												
	Transportation												
	Services												
	Other Industry												
VALUE ADDED	Employees	Employee compensation								GROSS DOMESTIC PRODUCT			
	Business Owners and Capital	Profit-type income and capital consumption allowances											
	Government	Indirect business taxes											

[1] Input/Output Model, https://en.wikipedia.org/wiki/Input%E2%80%93output_model

Following the algebraic transaction table is presented:

Table 6: Algebraic transactions table, Source: http://www.rri.wvu.edu/WebBook/Schaffer/chap04.html

Selling sector \ Buying sector	Extraction (1)	Construction (2)	Manufacturing (3)	Trade (4)	Services (5)	Households (6)	Final demand and exports (7)	Total demand (8)
Extraction (1)	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	e_1	z_1
Construction (2)	x_{21}	x_{22}	x_{23}	x_{24}	x_{25}	x_{26}	e_2	z_2
Manufacturing (3)	x_{31}	x_{32}	x_{33}	x_{34}	x_{35}	x_{36}	e_3	z_3
Trade (4)	x_{41}	x_{42}	x_{43}	x_{44}	x_{45}	x_{46}	e_4	z_4
Services (5)	x_{51}	x_{52}	x_{53}	x_{54}	x_{55}	x_{56}	e_5	z_5
Households (6)	x_{61}	x_{62}	x_{63}	x_{64}	x_{65}	x_{66}	e_6	z_6
Final payments (7)	v_1	v_2	v_3	v_4	v_5	v_6	--	--
Imports (8)	m_1	m_2	m_3	m_4	m_5	m_6	--	--
Total inputs (9)	q_1	q_2	q_3	q_4	q_5	q_6	--	--

The relations between the different sectors of an economy can be depicted by a system of linear equations. The generic form of the matrix is:

$X_1=X_{11}+X_{12}+...+X_{1n}+Z_1$
$X_2=X_{21}+X_{22}+...X_{2n}+Z_2$
.
.
.
$X_n=X_{n1}+X_{n2}+...+X_{nn}+Z_n$

Where X_1 is the total product of sector 1
X_{11} is the product of sector 1 used by sector 1,
X_{21} is the product of sector 2 used by sector 1 etc.
And,
Z_1 is the final demand of sector 1.

In order the structure of cost of production to be found, the technological coefficients must be defined. Technological coefficients (a_{ij}) indicate the used technology in each economy and expressed through the Leontief's inverse matrix:

$X=(I-A)^{-1} Z$

Where,
X is the total product of the economy for a year

And $(I-A)^{-1}$ is the inverse matrix which is the solution of the input-output system of linear equations is of great importance due to the fact that defines the overall results, both direct and indirect, when the final demand increases or decreased of one unit. In other words, through the inverse matrix we can export the holistic fluctuations in all sectors of an economy (national or regional) that take place when the final demand is altered by one unit.

4.2 Inoperability Input–Output Model for Critical Infrastructure Resilience

This section is based on selected parts from: Olaf Jonkeren & Georgios Giannopoulos (2014) ANALYSING CRITICAL INFRASTRUCTURE FAILURE WITH A RESILIENCE INOPERABILITY INPUT–OUTPUT MODEL, Economic Systems Research, 26:1, 39-59)

The Inoperability Input-Output Model (IIM) firstly proposed by (Santos and Haimes, 2004) can be seen as an specific extension of Leontief's Input-Output Model measuring the relative degradation of an infrastructure's or sector's capacity to deliver its intended output due to internal failures or external pertubations (Y.Y Haimes et al., 2005a; Y. Y Haimes et al., 2005b).

Therefore, it was extended by Haimes et al. (2005a; 2005b) by adding the ability to recover from disruptive events, which changed the static IIM into a dynamic one (the DIIM). Barker and Santos (Barker and Santos, 2010) introduced the Dynamic Inventory DIIM with the ability to model effects of resilience measures which delay the activation of an infrastructure operation due to the limited access to the sort of an inventory. Inventory represents the sum of finished goods or the procedure providing goods or services to other infrastructures or sectors or final consumers. The equation that follows, presents the Inventory DIIM Barker and Santos (2010).

$$q_i(t+1) = \begin{cases} q_i(t) + k_{ii}\left[c_i^*(t) - q_i(t) + \sum_{j=1}^{n} a_{ij}^* q_j(t)\right] \\ \quad \text{if } s_i(t+1) \geq p_i(t+1)x_i(t+1), \\ \max\begin{cases} p_i(t+1) - \dfrac{s_i(t+1)}{x_i(t+1)} \\ q_i(t) + k_{ii}\left[c_i^*(t) - q_i(t) + \sum_{j=1}^{n} a_{ij}^* q_j(t)\right] \end{cases} \\ \quad \text{if } 0 < s_i(t+1) < p_i(t+1)x_i(t+1), \\ \max\begin{cases} p_i(t+1) \\ q_i(t) + k_{ii}\left[c_i^*(t) - q_i(t) + \sum_{j=1}^{n} a_{ij}^* q_j(t)\right] \end{cases} \\ \quad \text{if } s_i(t+1) = 0, s_i(t) > 0, \\ q_i(t) + k_{ii}\left[c_i^*(t) - q_i(t) + \sum_{j=1}^{n} a_{ij}^* q_j(t)\right] \\ \quad \text{if } s_i(t+1) = s_i(t) = 0. \end{cases}$$

$q_i(t)$: the inoperability of sector *i* at the end of time t expressed by the ratio of unrealized production with respect to the "as planned" production level of the sector

$p_i(t)$: is similar to $q_i(t)$ but describes inoperability of the production process of sector I at the end of time t only due to physical disruption of that process

$s_i(t)$: is the inventory level and quantifies the amount of finished goods inventory in sector I remaining at the end of time t.

$x_i(t)$: is the total anticipated output of sector i between t-1 and t

k_{ii}: is the sectoral recovery coefficient valued between 0 and 1, indicating how fast sector i recovers from production inoperability

4.3 The Social Accounting Matrix

The core of Social Accounting Matrix is based on Input-Output Models as it was presented in section 4.1 of this report.

According to OECD's Glossary of Statistical Terms:

"A social accounting matrix (SAM) is a means of presenting the national accounts in a matrix which elaborates the linkages between a supply and use table and institutional sector accounts. A typical focus of a SAM on the role of people in the economy may be reflected by, among other things, extra breakdowns of the household sector and a disaggregated representation of labour markets (i.e., distinguishing various categories of employed persons)."[2]

Table 7: Indicative Social Accounting Matrix, Source: https://en.wikipedia.org/wiki/Social_accounting_matrix

	Firm	Household	Government	Rest of Economy	Net Investment	Total (Received)
Firm		C	G_F	$(X-M)_K$	I	$C+G_F+(X-M)_K+I$
Household	W		G_H	$(X-M)_C$		$W+G_H+(X-M)_C$
Government	T_F	T_H				T_F+T_H
Rest of Economy	$(X-M)_K$	$(X-M)_C$				$(X-M)_K+(X-M)_C$
Net Investment		S_H	S_G			S_H+S_G
Total (Expended)	$W+T_F+(X-M)_K$	$C+T_H+(X-M)_C+S_H$	$G_F+G_H+S_G$	$(X-M)_C+(X-M)_K$	I	

Abbreviations: Capital letters: Taxes, Wages, iMports, eXports, Savings, Investment, Consumption, Government Transfer Subscripts: Firms, Households, Government, Consumption Goods, K: Capital Goods

SAMs can be organised in many different ways, but essentially they provide information on interactions between (Antonopoulos and Kim, 2008):
(1) Production activities (productive sectors of the economy) and commodities used (intermediate goods used in production);
(2) Factors of production (capital and labour);
(3) Institutions (households, firms and government);
(4) Capital account (the financial side of the macroeconomy); and
(5) Rest of the world (imports, exports and other financial flows)

These accounts are symmetrically arranged (in rows and columns) forming a square matrix that traces the origin and destination of expenditures and income received. In addition to providing a consistent framework of national accounts, a SAM incorporates the distributional and social dimensions of an economy.

[2] SOCIAL ACCOUNTING MATRIX (SAM), https://stats.oecd.org/glossary/detail.asp?ID=2476

Table 8: Simplified Schematic Social Accounting Matrix, Source: (Defourny and Thorbecke, 1984)

			EXPENDITURES						
			ENDOGENOUS			EXOGENOUS			TOTALS
			FACTORS	HOUSEHOLDS	PRODUCTIVE ACTIVITIES	GOVERNMENT	REST OF THE WORLD	CAPITAL ACCOUNT	
RECEIPTS OR INCOMES	ENDO-GENOUS	FACTORS	0	0	T_{13}	X_{14}	X_{15}	X_{16}	Y_1
		HOUSEHOLDS	T_{21}	T_{22}	0	X_{24}	X_{25}	X_{26}	Y_2
		PRODUCT ACTIVITY	0	T_{32}	T_{33}	X_{34}	X_{35}	X_{36}	Y_3
	EXO-GENOUS	GOVERNMENT	L_{41}	L_{42}	L_{43}	t_{44}	t_{45}	t_{46}	Y_4
		REST OF WORLD	L_{51}	L_{52}	L_{53}	t_{54}	t_{55}	t_{56}	Y_5
		CAPITAL ACCOUNTS	L_{61}	L_{62}	L_{63}	t_{44}	t_{45}	t_{46}	Y_6
	TOTALS		Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	

The model of Social Accounting follows (OKUYAMA, 2009):

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} X_{11} & 0 & X_{13} \\ X_{21} & 0 & 0 \\ 0 & X_{32} & X_{33} \end{pmatrix} + \begin{pmatrix} f_1 \\ f_2 \\ f_3 \end{pmatrix}$$

Where:
x_1 is gross output,
x_2 is income of factors,
x_3 is income of private sector (including household and companies),
X_{11} is transaction between production activities (input-output relationships),
X_{13} is private consumption,
X_{21} is value added payments,
X_{32} is income to private sector,
X_{33} is inter-institution transfer,
f_1 is final demand for production activities,
f_2 is final demand for factor, and
f_3 is final demand for private sector.
Then, the above equation can be rewritten with direct input coefficient matrix as follows:

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} A_{11} & 0 & A_{13} \\ A_{21} & 0 & 0 \\ 0 & A_{32} & A_{33} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} + \begin{pmatrix} f_1 \\ f_2 \\ f_3 \end{pmatrix}$$

Solving this yields the accounting multiplier matrix:

$$x_n = (I - A_n)^{-1} f_n = M_a f_n$$

Where:

$$x_n = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix}, \quad A_n = \begin{pmatrix} A_{11} & 0 & A_{13} \\ A_{21} & 0 & 0 \\ 0 & A_{32} & A_{33} \end{pmatrix}, \quad f_n = \begin{pmatrix} f_1 \\ f_2 \\ f_3 \end{pmatrix}$$

And M_a is the accounting multiplier matrix.
The accounting multiplier matrix (M) plays the same role, as Leontief's inverse matrix (I) in IO model. Once more, through M the direct and indirect effects could be defined due to any changes in final demand.

4.4 Economic Resilience Definitions

This section is based on selected parts from: Rose, A., 2009, Economic resilience to disasters: http://www.resilientus.org/wp-content/uploads/2013/03/Research_Report_8_Rose_1258138606.pdf

Table 9: Types of Economic Resilience

Types of Economic Resilience	
Name	Description
Economic resilience	is noted as an attribute of the economy in studies of economic shocks
Static economic resilience	as the ability of an entity or system to maintain function (e.g., continue producing)
Dynamic economic resilience	is the speed at which an entity or system recovers from a severe shock to achieve a desired state
Inherent resilience	refers to the ordinary ability to deal with crises (e.g., inventories, the ability of individual firms to substitute other inputs for those curtailed by an external shock, or the ability of markets to reallocate resources in response to price signals)
Adaptive resilience	refers to the ability in crisis situations to maintain function on the basis of ingenuity or extra effort (e.g., increasing input substitution possibilities in individual business operations, recontracting or strengthening the market by providing information to match suppliers with customers)

4.4.1 Measuring the Economic Resilience

Direct static economic resilience (DSER) refers to the level of the individual firm or industry (micro and meso levels) and corresponds to what economists refer to as "partial equilibrium" analysis, or the operation of a business or household entity itself. Total static economic resilience (TSER) refers to the economy as a whole (macro level) and would ideally correspond to what is referred to as "general equilibrium" analysis, which includes all of the price and quantity interactions in the economy.

An operational measure of DSER is the extent to which the estimated direct output reduction deviates from the likely maximum potential reduction given an external shock, such as the curtailment of some or all of a critical input:

$$DSER = \frac{\%\Delta DY^m - \%\Delta DY}{\%\Delta DY^m},$$

where

$\%\Delta DY^m$ is the maximum percent change in direct output and
$\%\Delta DY$ is the actual percent change in direct output.

Analogously, the measure of total economic resilience (TSER) to input supply disruptions is the difference between a linear set of indirect effects, which implicitly omits resilience, and a non-linear outcome, which incorporates the possibility of resilience. The former would be consistent with the context of an I-O model, which is inherently linear and which implicitly omits the possibility of resilience. From an operational modelling standpoint, TSER is the difference between the linear I-O multiplier and comprehensive, non-linear model (e.g., CGE or econometric) impacts as follows:

$$TSER = \frac{\%\Delta TY^m - \%\Delta TY}{\%\Delta TY^m} = \frac{M \times \%\Delta DY^m - \%\Delta TY}{M \times \%\Delta DY^m},$$

where

M is the economy-wide input-output multiplier,
$\%\Delta TY^m$ is the maximum percent change in total output, and
$\%\Delta TY$ is the actual percent change in total output.

4.4.2 An electricity sector disruption as case study to measure economic resilience:

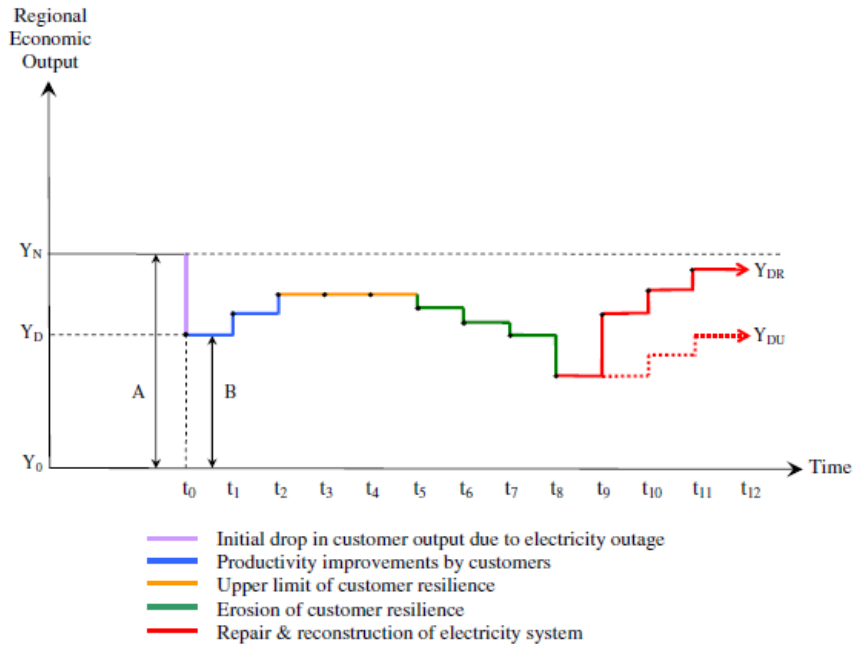


Figure 3: Static and Dynamic resilience in the context of business interruption, Source: (Rose, 2007)

The normal level of output proceeds at Y_N until some external shock takes place (Rose, 2007). The result of this disruption in the presence of static resilience is a reduction in output to Y_D, as opposed to a total shutdown of the economy to Y_0. That is, static resilience is the ratio of the avoided drop in output and the maximum potential drop to Y_0, or $(Y_D-Y_O)/(Y_N-Y_O)$, or the ratio of line segments B and A (B/A). In the initial period, adaptive behaviour (ingenuity) is likely to be minimal, and the measure is likely to be dominated by inherent resilience.

Regarding the dynamics of the case, the main question is the pattern of recovery i.e. how much recovery takes place in each time period and why. In Figure 3 the case refers to the destruction of a major transformer that requires several time periods (t_i) to replace. The upward movement in output following the initial decline due to the disaster, Y_D, would represent basic improvements in resilience through adaptive behavior in t_1 and t_2. A temporary equilibrium is reached and persists until t_5, when deterioration in static resilience might start to take place (e.g., inability to sustain Draconian conservation, permanent loss of customers that reduces the possibility of production rescheduling and even dissipation of inherent resilience such as substitution possibilities). The next upswing in Y_D does not take place until t_9, and then as a combination of repair/replacement of the transformer (and its phasing in of operation) and of remaining static resilience capabilities.

Dynamic resilience would then be defined as the loss reducing effect of hastening repair and reconstruction of the capital stock over and above business as usual practices. It is best defined in terms of its total effect:

$$TDER = \sum_{t=0}^{n} Y_{DR} - \sum_{t=0}^{m} Y_{DU},$$

, where m>n.

5 Multi-Criteria Decision Analysis (MDCA)

5.1 Multi-Criteria Analysis in general

Multi-Criteria Analysis (MCA) is a decision-making tool developed for complex problems. By using MCA the members don't have to agree on the relative importance of the criteria or the rankings of the alternatives. Each member enters his or her own judgements, and makes a distinct, identifiable contribution to a jointly reached conclusion. The method can be used in the foresight working group to reach a consensus about the best project or scenario.

MCA techniques are diverse in both the kinds of problem that they address (for example prioritization of programs as well as single option selection) and in the techniques that they employ, ranging from decision conferencing to less resource intensive processes.

As is clear from a growing literature, there are many MCA techniques and their number is still rising. There are several reasons why this is so:

- There are many different types of decision that fit the broad circumstances of MCA
- The time available to undertake the analysis may vary
- The amount or nature of data available to support the analysis may vary
- The analytical skills of those supporting the decision may vary, and
- The administrative culture and requirements of organizations vary.[3]

This method is generally used at the end of a process that clears up the different options.

According to United Nations Framework Convention on Climate Change, Multicriteria analysis or multiobjective decision making is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach (such as cost-benefit analysis) falls short, especially where significant environmental and social impacts cannot be assigned monetary values. MCA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria.

5.2 Procedure of MCDA-methods

The basic idea of MCDA (Multi-Criteria Decision Analysis) methods is to evaluate the performance of alternative courses of action (e.g. management or policy options) with respect to criteria that capture the key dimensions of the decision-making problem (e.g. ecological, economic, and social sustainability), involving human judgment and preferences. MCDA methods are integrative evaluation methods in the sense that they combine information about the performance of the alternatives with respect to the criteria (scoring) with subjective judgements about the relative importance of the evaluation criteria in the particular decision-making context (weighting).[4] The steps in a MCDA process are presented in Figure 4.

[3] Multi-criteria analysis: a manual (2009), http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf Department for Communities and Local Government: London

[4] Heli Saarikoski (SYKE, Finland) at al., Multi-criteria decision analysis (MCDA) in ecosystem service valuation, OpenNESS operationalisation of Natural Capital and Ecosystem Services

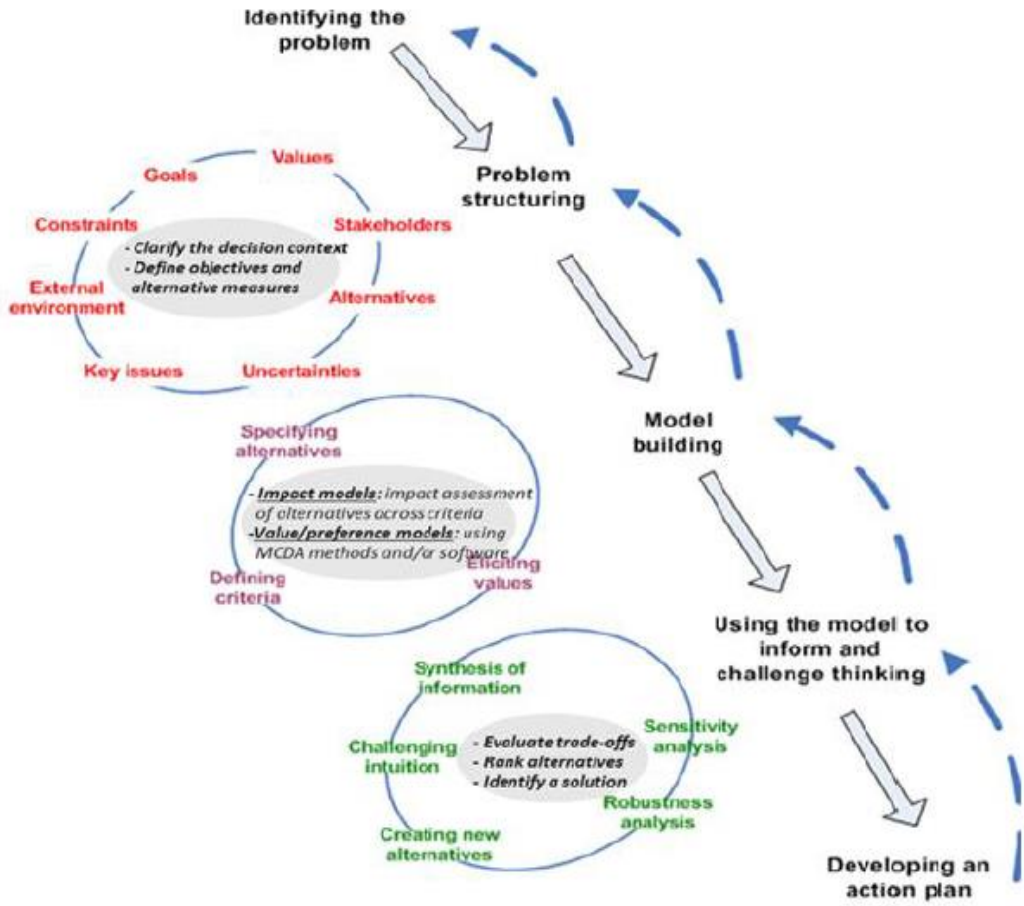


Figure 4: An illustration of a MCDA process, Source: Catrinu-Renstrom at al. (2013), modified from Belton and Stewart (2002).

The application to and integration of MCDA in environmental planning and decision making requires an assessment of:

- When MCDA should be introduced into the process

- How MCDA affects the design of the decision process

- How are MCDA and the decision process integrated

- How should the decision makers and stakeholders (advisory boards, steering groups) be engaged in the MCDA process

- How the results of MCDA will be used in decision making[5]

According to Catrinu-Renstrom at al. (2013) MCDA can be helpful in many situations:

- As a framework for the whole planning and decision making process
- In the identification and structuring stakeholders' objectives
- In the development of new alternatives

[5] Multi-criteria analysis applied to environmental impacts of hydropower and water resources regulation projects (2017), https://www.researchgate.net/publication/294823876_Multicriteria_analysis_applied_to_environmental_impacts_of_hydropower_and_water_resources_regulation_projects#pf17

- For comprehensive evaluation/ranking of alternatives
- For incorporating stakeholders' values and knowledge in decision making
- For describing stakeholders' values and their impacts on outcomes
- For facilitating interaction and learning between experts, authorities and stakeholders
- For understanding the implications of uncertainties
- For creating shared understanding and commitment among stakeholders
- For finding widely acceptable (consensus/compromise) solutions[6]

Figure 6.1 Applying MCDA: Detailed steps

1. **Establish the decision context.**
   - 1.1 Establish aims of the MCDA, and identify decision makers and other key players.
   - 1.2 Design the socio-technical system for conducting the MCDA.
   - 1.3 Consider the context of the appraisal.
2. **Identify the options to be appraised.**
3. **Identify objectives and criteria.**
   - 3.1 Identify criteria for assessing the consequences of each option.
   - 3.2 Organise the criteria by clustering them under high-level and lower-level objectives in a hierarchy.
4. **'Scoring'. Assess the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion.**
   - 4.1 Describe the consequences of the options.
   - 4.2 Score the options on the criteria.
   - 4.3 Check the consistency of the scores on each criterion.
5. **'Weighting'. Assign weights for each of the criterion to reflect their relative importance to the decision.**
6. **Combine the weights and scores for each option to derive an overall value.**
   - 6.1 Calculate overall weighted scores at each level in the hierarchy.
   - 6.2 Calculate overall weighted scores.
7. **Examine the results.**
8. **Sensitivity analysis.**
   - 8.1 Conduct a sensitivity analysis: do other preferences or weights affect the overall ordering of the options?
   - 8.2 Look at the advantage and disadvantages of selected options, and compare pairs of options.
   - 8.3 Create possible new options that might be better than those originally considered.
   - 8.4 Repeat the above steps until a 'requisite' model is obtained.

Figure 5: Applying MCDA: Detailed steps, Source: Multi-criteria analysis: a manual (2009), http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf Department for Communities and Local Government: London

[6] Multi-criteria analysis applied to environmental impacts of hydropower and water resources regulation projects (2017), https://www.researchgate.net/publication/294823876_Multicriteria_analysis_applied_to_environmental_impacts_of_hydropower_and_water_resources_regulation_projects#pf17

Procedure of MCDA methods:

1. Establish the decision context. Declaration of the main objective; Determination of decision makers and other key players; Determination of all stakeholders (influenced by the chosen alternative)

2. Identify the options to be appraised. Discrete number of alternatives; Describe alternatives (characteristics), all characteristics/criteria have to be define for all alternatives. Perhaps there will discovered new alternatives which can be included in the set of alternatives.

3. Identify objectives and criteria. Definition of the main objective and splitting into sub-objectives. Foundation for hierarchy of criteria, identify criteria for assessing the consequences of each option.
   Criteria have to be complete (describe each alternative and their attributes); Avoid redundancy (two or more criteria may not follow the same objective – e.g. low operating costs and low energy costs); Independent (low assessment in one criterion may not lead automatically to low assessment in another criterion) and well-structured for minimization of data collection effort (number of criteria, 6-20 criteria, more if there are complex decisions).

4. 'Scoring'. Assess the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion. Describe the consequences of the options; Score the options on the criteria; Check the consistency of the scores on each criterion.
   Identification of criteria as top-down approach or bottom-up approach; Top-down is starting from a main objective to the sub objectives and criteria; Bottom-up approach is based on the alternatives there will be derived strengths and weaknesses derivation of criteria which are relevant to the decision.

5. ´Weighting´. Assign weights for each of the criterion to reflect their relative importance to the decision. Attitude of decision makers regarding to an alternative and its consequences. Generating a utility function for assessing the preference of an alternative regarding to a particular criterion. Degree of achievement/value of benefit describe the preference of an alternative (possibly, between 0 (low value of benefit) and 1 (high value of benefit)). Weighting of criteria for ensuring the importance of a criterion for the overall decision problem.

6. Combine the weights and scores for each option to derive an overall value. Creation of a decision table which include criteria, alternatives and their attributes for assessing the right characteristics of the alternatives.

	Criterion A	Criterion B	Criterion C	Criterion D	Criterion D	Criterion E
Option 1						
Option 2						
Option 3						
Criterion weight						

Generic Decision Matrix: Weighted Scores

	Criterion A	Criterion B	Criterion C	Criterion D	Criterion D	Criterion E	Total Benefit
Option 1	0	0	0	0	0	0	0
Option 2	0	0	0	0	0	0	0
Option 3	0	0	0	0	0	0	0
Criterion weight	0	0	0	0	0	0	

Figure 6: Decision Matrix - Template

As the default criteria, it can be use resistance indicators defined by categories and sub-categories, and metrics.

7. <u>Assessment of subjective criteria weighting. Examine the results.</u>

Assigning of the **relevance** of a criterion from the perspective of decision makers and stakeholders. Usually weights between 0 and 1, ∑ weights = 1.

SMART (Simple Multi-Attribute Rating Technique)

Most important criterion assigned 100 points, it is reference criterion. Other criteria assigned points in relation to reference criterion. In the end: sum up all points from each criteria

$$\frac{points\ for\ a\ certain\ criterion}{sum\ of\ all\ points\ fraom\ each\ criteria} = weight\ for\ certain\ criterion$$

Other methods are as follows:

SWING:

For each criterion there exist two different characteristics (best and worst option)
Decision maker or stakeholder have to select the criterion for which it is most important to define the better characteristic → 100 points
Same procedure for other criteria → gradation for the following criteria
Analogous procedure as in SMART-method

SIMOS:

Ranking of all criteria (equal ranking position possible, blank rank possible to assess distances)
Ranking position and number of criteria result in criteria weights
$r_{min} + (f-1) * \frac{r - r_{min}}{r_{max} - r_{min}}$ = point value
Analogous procedure as in SMART-method

It is suggested to use the SMART, Simple Multi-Attribute Rating Technique in further work.
The Simple Multi Attribute Rating Technique (SMART):

The SMART technique is based on a linear additive model. This means that an overall value of a given alternative is calculated as the total sum of the performance score (value) of each criterion (attribute) multiplied with the weight of that criterion.

The main stages in the analysis are (adapted from Olson (1996)):

Stage 1: Identify the decision-maker(s)

Stage 2: Identify the issue of issues: Utility depends on the context and purpose of the decision

Stage 3: Identify the alternatives: This step would identify the outcomes of possible actions, a data gathering process.

Stage 4: Identify the criteria: It is important to limit the dimensions of value. This can be accomplished by restating and combining criteria, or by omitting less important criteria. It has been argued that it was not necessary to have a complete list of criteria. Fifteen were considered too many, and eight was considered sufficiently large. If the weight for a particular criterion is quite low, that criterion need not be included. There is no precise range of the number of criteria appropriate for decisions.

Stage 5: Assign values for each criteria: For decisions made by one person, this step is straightforward. Ranking is a decision task that is easier than developing weights, for instance. This task is usually more difficult in group environments. However, groups including diverse opinions can

Result in a more thorough analysis of relative importance, as all sides of sides of the issue are more likely to be voiced. An initial discussion could provide all group members with a common information base. This could be followed by identification of individual judgments of relative ranking.

Stage 6: Determine the weight of each of the criteria: The most important dimension would be assigned an importance of 100. The next-most-important dimension is assigned a number reflecting the ratio of relative importance to the most important dimension. This process is continued, checking implied ratios as each new judgment is made. Since this requires a growing number of comparisons there is a very practical need to limit the number of dimensions (objectives). It is expected that different individuals in the group would have different relative ratings.

Stage 7: Calculate a weighted average of the values assigned to each alternative: This step allows normalization of the relative importance into weights summing to 1.

Stage 8: Make a provisional decision

Stage 9: Perform sensitivity analysis

In SMART, ratings of alternatives are assigned directly, in the natural scales of the criteria. For instance, when assessing the criterion “cost” for the choice between different road layouts, a natural scale would be a range between the most expensive and cheapest road layout. In order to keep the weighting of the criteria and the rating of the alternatives as separate as possible, the different scales of criteria need to be converted into a common internal scale. In SMART, this is done mathematically by the decision-maker by means of a Value Function. The simplest and most widely used form of a value function method is the additive model, which in the most simple cases can be applied using a linear scale (e.g. going from 0 to 100).

8. <u>Aggregation and obtaining a rank order</u>
    - Based on objectives, alternatives, criteria, preferences and weights → ranking of alternatives
    - Define the **degree of achievement** for each alternative
    - Calculation with the assistance of software tools
9. <u>Sensitivity analysis</u>
    - validation of results → **variation of input factors**
        - Changing of the results?
    - Variation of **subjective, qualitative and difficult quantifiable** Input factors (e.g. criteria weights)
    - **Insensitivity Intervals** can show a range of variation in which an input factor can change their characteristic without changing the overall result → solid solution!

5.3 Types of Multi-Criteria Analysis approaches

Several different MCDA rules have been implemented in the GIS environment for tackling environmental problems. Multi-criteria decision-making problems can be classified on the basis of the major components of MCDA: multi-objective decision-making (MODM) versus multi-attribute decision making (MADM). The clearest separation of these methods is based on whether there are one or multiple preferences or scenarios. The MODM approaches are mathematical programming model oriented methods with their multiple objectives definitely in conflict, while MADM methods are data oriented with multiple attributes that are either complementary or can be prioritized according to decision makers preferences.[7]

1. **Multi-Objective Decision Making (MODM)**

- Infinite number of alternatives
- Consideration a set of objective functions
- Searching for optimal solution

2. **Multi-Attribute Decision Making (MADM)**

MADM is one of the quantitative research methods. It can give managers many dimensions to consider related elements, and evaluate all possible options under variable degrees.

Multiple Attribute Decision Making (MADM) involves "making preference decisions (such as evaluation, prioritization, selection) over the available alternatives that are characterized by multiple, usually conflicting, attributes". The problems of MADM are diverse, and can be found in virtually any topic.[8]

- Finite number of alternatives
- Take alternatives for granted (input from D4.6), choose the best one
- compromise solution (exception: one alternative dominate all other alternatives in each criteria)
- no conversion into an unified measuring unit necessary

<u>Different approaches within MADM</u>

2.1. Classic procedures

2.1.1. Utility analysis

2.1.2. Multi attribute utility theory (MAUT) – advancement of utility theory

2.1.3. Analytic Hierarchy Process

Decision makers must have a clear understanding of their preferences, starting from objective functions, next step is the calculation of the part-worth utilities. Addition of part-worth utilities generate the total utility of an adaptation measure.

2.2. Outranking

[7] GIS-based multicriteria decision analysis applied for environmental issues; the Greek experience.. (n.d.) >The Free Library. (2014). Retrieved Aug 21 2017 from https://www.thefreelibrary.com/GISbased+multicriteria+decision+analysis+applied+for+environmental...-a0323038201

[8] Fred S. Azar, "Multiattribute Decision-Making: Use of Three Scoring Methods to Compare the Performace of Imaging Techniques for Breast Cancer Detection", January 2000.

2.2.1.ELECTRE

2.2.2.PROMETHEE

- Avoid disadvantages of classic procedures: decision makers must not have a clear definition of their preferences
- Objective of outranking is to enhance the transparency of the decision making process
- Pairwise comparisons for identification of the preference functions of decision makers

➔ Assistance in calculation of classic procedures and outranking methods by software-tools

5.4 Utility analysis

- Evaluation of the degree of achievement for different alternatives
- Objective: Determination of a point value for each alternative or a ranking order for all alternatives
- Along the value range of each criterion there have to be define certain degrees of achievement
  → transformation of criteria into one value unit (→degree of achievement→ **loss of information**)

criteria/objectives	alternative A	alternative B	alternative C
price	6	4	3
save human lives	5	6	4
preservation of infrastructure	3	3	6
business continuity	4	4	5

Point value: 1 = very good; 6 = insufficiently

- aggregation of point values through weighted multiplication or addition (criteria weighting - extern)
- Criteria weighting (e.g. with help of SMART-method)

criteria/objectives	Weight (w_j)	alternative A	alternative B	alternative C
price	0,4	6	4	3
save human lives	0,3	5	6	4
preservation of infrastructure	0,2	3	3	6
business continuity	0,1	4	4	5

- Ranking order:
  - W_j = weight of criterion j
  - Z_{aj} = degree of achievement of alternative a regarding criterion j

criteria/objectives	alternative A	alternative B	alternative C
price	6*0,4	4*0,4	3*0,4
save human lives	5*0,3	6*0,3	4*0,3
preservation of infrastructure	3*0,2	3*0,2	6*0,2
business continuity	4*0,1	4*0,1	5*0,1
Total value(Z_{aj})	4,9	4,4	4,1

- Critical view:

- Unrestricted compensation of criteria among each other (monetary procedure)
- Information loss when transforming characteristics of a higher scale of measurement into lower scale of measurement

5.5 Outranking ELECTRE III & PROMETHEE II in general

- Take into account aims of multiple decision makers
- Main question: **is one alternative at least as good as another**
- formulated with:
  - a set of alternatives a_i
  - a set of criteria c_j
  - $g_j(a_j)$ = **performance** of an alternative i with respect to criterion j
  - q_j = **indifference threshold** for criterion j
    - **beneath** this difference decision maker is **indifferent** between two alternatives a_k and a_l
    - $a_k \, I \, a_l \Leftrightarrow g_j(a_k) - g_j(a_l) \leq q_j$
  - p_j = **preference threshold** for criterion j
    - **above** this difference decision makers **strongly prefers** a_k over a_l
    - $a_k \, P \, a_l \Leftrightarrow g_j(a_k) - g_j(a_l) > p_j$
  - zone of **weak preference** between indifference and strong preference
    - $a_k \, Q \, a_l \Leftrightarrow q_j < g_j(a_k) - g_j(a_l) \leq p_j$
    - when criteria is ordinal or descriptive the weak preference does not make sense → q_j and $p_j = 0$ → only indifference or strong preference between alternatives
- usually decision makers define the weights and analysts choose the value for thresholds
- sensitivity analysis of the results are essential and important

5.5.1 ELECTRE III

<u>General characteristics</u>

- pairwise comparison of two alternatives regarding one criterion
- dealing with compensation (boundary value for compensation of a bad value for a criterion with good values of another criterion)
- dealing with uncertainty (**indifference limits**, **significance limits**)
- coefficients for criteria weights have to determine in an external investigation

<u>Input data</u>

- characteristic values can define as **qualitative and quantitative** → information matrix
- information should be **completely** and defined on a **ordinal scale**
- weights of criteria should be normed an in total sum up to 1
- specification of preferences
- **parameter of indifferences** → for defining a range of values in which no significant difference between two alternatives can be discover (integration of knowledge regarding uncertainty and fuzziness in the input data)
- **Significance parameter (preference parameter)** → identify differences among alternatives as substantial

- **veto parameter** → ensuring that alternatives with inacceptable criteria characteristics were evaluated as inacceptable alternatives

Procedure (Kangas, A., Kangas, J., Pykäläinen, J.)

- determination of **concordance indices** based on parameter for indifference and significance
  → testing assumption: "option a is not worse than option b with respect to a criterion j"
  → calculation of **concordance matrix** under consideration of criteria weights
- calculation of **discordance indices** based on veto parameters → counter-argument for concordance assumption
- determination of **credibility index** → summary of concordance indices and discordance indices
- **distillation** → iterative process for determination of one or two ordinal ranking orders based on the credibility index (testing of incomparability with consistency tests)

- Designation of input data:
  - A = set of alternatives
  - a, b, c, d, … describe the certain alternatives
  - g_j (a) = characterization value of alternative a regarding criterion j
  - w_j = weight of criterion j
  - q_j = indifference parameter for criterion j
  - p_j = significance parameter for criterion j
  - v_j = veto parameter for criterion j
  - α and β = distillation parameters
  - requirement: v > p > q

1. Determination of partial concordance indices
   - partial concordance index:

$$c(a_k, a_l) = \sum_{j=1}^{p} w_j c_j\,(a_k, a_l)$$

with:

w_j = relative importance (weight)
$c_j(a_k,a_l)$ = local concordance index

$$c_j(a_k, a_l) = \begin{cases} 0, if\ g_j(a_l) - g_j(a_k) \geq p_j \\ 1, if\ g_j(a_l) - g_j(a_k) \leq q_j \\ \dfrac{p_j - \left(g_j(a_l) - g_j(a_k)\right)}{p_j - q_j}, otherwise \end{cases}$$

- $c_j = 0$ → characteristic value of $g_j(a_l) \geq g_j(a_k)+p_j$
  → **no preference** for alternative a_k over alternative a_l

- $c_j = 1$ → characteristic value of $g_j(a_l) \leq g_j(a_k)+q_j$
  → **strong preference** for alternative a_k over alternative a_l
- $0 < c_j < 1$ → **weak preference** for alternative a_k over alternativ a_l (**fuzzy measurement**)

2. Combined concordance matrix
   - **Aggregation** of partial concordance indices using criteria weights:
   - $c(a_k,a_l)=\sum_1^j w_j c_j(a_k,a_l)$
3. Determination of partial discordance indices
   - Investigation whether **veto conditions (veto threshold v_j)** are fulfilled or not
   - Veto threshold for computing the discordance index
   - Discordance index is used to model the degree of compensation between criteria
   - If veto condition is fulfilled → **discordance index (d_j)** = 1
     → **$g_j(a_l) > g_j(a_k)+v_j(a)$** → rejection of assumption: "alternative a_k not worse than alternative a_l"
   - **discordance index (d_j)= 0**
     → **$g_j(a_l) \leq gj(a_k)+p_j(a)$** → alternative a_k not substantial worse than alternative a_l
   - **$0 < (d_j) < 1$** → partial disagreement for assumption "alternative a_k not worse than alternative a_l"
     → fuzzy measurement for correctness of assumption: alternative a_k inacceptable worse than alternative a_l
   - The closer v_j is to p_j, the more important criterion j can be considered

$$\mathrm{d}_j(\mathrm{a}_k,\mathrm{a}_l) = \begin{cases} 0, if\ g_j(a_l) - g_j(a_k) \leq p_j \\ 1, if\ g_j(a_l) - g_j(a_k) \geq v_j \\ \dfrac{\left(g_j(a_l) - g_j(a_k)\right) - p_j}{v_j - p_j}, otherwise \end{cases}$$

4. Derivation of credibility index
   - Integration/consolidation of concordance indices and discordance indices
   - Starting point: concordance indices → check if veto condition fulfilled for a certain criteria → veto condition fulfilled: reduce of credibility index (i.e. checking discordance indices if there are values > 0)
   - Summary of arguments that argue for or against an alternative ($\mathrm{S}(\mathrm{a}_k,\mathrm{a}_l)$ = degree of outranking)

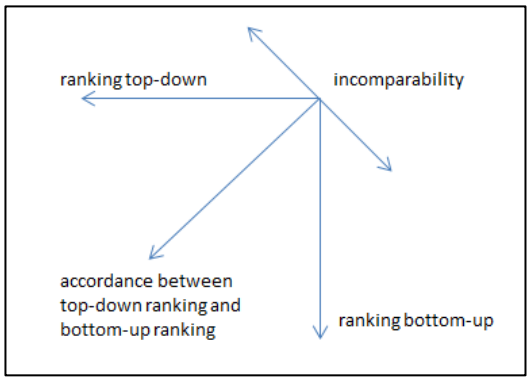
$$\mathrm{S}(\mathrm{a}_k,\mathrm{a}_l) = \begin{cases} \mathrm{C}(\mathrm{a}_k,\mathrm{a}_l), if\ J(\mathrm{a}_k,\mathrm{a}_l) = \emptyset \\ \mathrm{C}(\mathrm{a}_k,\mathrm{a}_l) \prod\limits_{j \in J(\mathrm{a}_k,\mathrm{a}_l)} \dfrac{1 - d_j(\mathrm{a}_k,\mathrm{a}_l)}{1 - C(\mathrm{a}_k,\mathrm{a}_l)}, otherwise \end{cases}$$

5. Distillation
   - Last step: determination of **two ranking orders** (upward and downward)
   - Test for each alternative: assumption "alternative a_k is at least as good as alternative a_l" significantly more credible as "alternative b is at least as good as alternative a"
     - Determination of **maximum credibility index (p_{max})**
     - Calculation of **cutting-level λ** (biggest value of credibility index under **(p_{max} – ε)**
     - **ε(λ) = αλ+β** (α=-0,15; β=0,3 → fixed, modify only if determination of ranking order is not possible)

- validation if **$p(a_k,a_l) > \lambda$** → alternative a_k is superior alternative a_l → **strenght** of alternative a_k
- **$p(a_l,a_k) > \lambda$** → alternative a_l is superior alternative a_k → **weakness** of alternative a_k
- ranking based on the **number of alternatives outranked** by a **certain alternative minus** the **number of alternatives which outrank the certain alternative**

- **descending ranking - top-down (Z_1):**
- altertnative with **bigger difference** between strenghts and weaknesses (amount of qualifications) → best alternative → rank 1 (m)
- delete **best** alternative and starting process from beginning
- **ascending ranking - botom-up (Z_2):**
- alternative with **smallest difference** between strenghts and weaknesses (amount of qualifications) → rank 1 (n)
- delete **worst** alternative and starting from the beginning
- if there are more than one alternative on a single rank → **reduce cutting-level** to decrease amount of alternatives with maximum (top-down) or minumum (bottom-up) amount of qualifications → ideally 1 alternative

6. Interpretation of results



- Result of distillation are two partial ranking orders → enter into a two-dimensional diagram
- **Final rank order (r_{final})** with:
- $r_{final} = (m+n) / 2$
- **incomparability (u)** with:
- $u = m-n$
- on the basis of avarage ranks it can happen that there are two alternatives with a similar rank → inclusion of decision makers; presentation of both partial orders (e.g. graphically)
- derivation of final ranking order in consultation with decision makers and stakeholders

7. Assistance of software tools
   - Assistance in the procedure conclusively the presentation of results not necessarily but facilitating the process
   - For sensitivity analysis software tools are absolutly necessary

8. Sensitivity analysis
   - Validation of results by (marginal) changing of input data
   - Incremental changing of input data (termination if necessary conditions are breached (e.g. criteria weight < 0; ELECTRE III-limit q < p < v exceeded)
   - Consideration of relation between criteria weights when changing them: save relation before changing weight of a criterion to spread or reduce the weights of the unchanged weights

5.5.2 PROMETHEE

Promethee method in general

Many MCDA methods are designed to solve ranking problems. The main goal of MCDA methods are to rank actions from the best to the worst one according to several criteria and to the preferences (preference functions) and priorities (weights) of the decision-maker. It is the case of PROMETHEE I and II. It is perfectly appropriate whenever one has to make a decision among a set of possible actions and to identify the best possible action. (Visual PROMETHEE manual)

The PROMETHEE (preference ranking organization method for enrichment evaluation) method was developed by Brans and Vincke in 1985. (Doumpos, M., and Zopounidis, C., 2004).

The PROMETHEE I method can provide the partial ordering of the decision alternatives, PROMETHEE II method can derive the full ranking of the alternatives. PROMETHEE II method based on generalized fuzzy numbers.

Many organizations have been using Promethee method, such as:

- private companies,
- public administrations,
- research centres,
- universities and
- Individuals worldwide.

Promethee method is used to evaluate several possible decisions or items according to multiple often conflicting criteria and on the end to identify the best possible decision.

How to manage activities: (Visual PROMETHEE manual)

- Define a new problem
  - Define the actions
  - Define the critera
  - Define the scenarios
  - Model preferences
  - Organize the criteria
  - Weigh the criteria
- Rank different actions
- Use the GAIA analysis
- Perform a sensitivity analysis
- Use weight presents
- Generate a report

Steps of the Promethee method

The procedural steps as involved in PROMETHEE II method are enlisted as below (Athawale, V. M. and Chakraborty, S. 2010)

Step 1: Normalize the decision matrix using the following equation:

$$R_{ij} = \left[X_{ij} - \min(X_{ij}) \right] \Big/ \left[\max(X_{ij}) - \min(X_{ij}) \right] \quad (i=1,2,\ldots,n : j=1,2,\ldots,m) \qquad (1)$$

where Xij is the performance measure of ith alternative with respect to j^{th} criterion.

For non-beneficial criteria, Eqn. (1) can be rewritten as follows:

$$R_{ij} = \left[\max(X_{ij}) - X_{ij} \right] \Big/ \left[\max(X_{ij}) - \min(X_{ij}) \right] \qquad (2)$$

Step 2: Calculate the evaluative differences of ith alternative with respect to other alternatives.

This step involves the calculation of differences in criteria values between different alternatives pair-wise.

Step 3: Calculate the preference function, Pj (i, i').

The following simplified preference function is adopted here:

$$P_j(i,i') = 0 \text{ if } R_{ij} \le R_{i'j} \qquad (3)$$

$$P_j(i,i') = (R_{ij} - R_{i'j}) \text{ if } R_{ij} > R_{i'j} \qquad (4)$$

Step 4: Calculate the aggregated preference function considering the criteria weights.

Aggregated preference function,

$$\pi(i,i') = \left[\sum_{j=1}^{m} w_j \, x \, P_j(i,i') \right] \Big/ \sum_{j=1}^{m} w_j \qquad (5)$$

Step 5: Determine the leaving and entering outranking flows as follows:

Leaving (or positive) flow for i^{th} alternative,

$$\varphi^{+}(i) = \frac{1}{n-1} \sum_{i'=1}^{n} \pi(i,i') \qquad (i \neq i') \qquad (6)$$

$$\varphi^{-}(i) = \frac{1}{n-1} \sum_{i'=1}^{n} \pi(i',i) \qquad (i \neq i') \qquad (7)$$

Step 6: Calculate the net outranking flow for each alternative:

$$\varphi(i) = \varphi^{+}(i) - \varphi^{-}(i) \tag{8}$$

Step 7: Determine the ranking of all the considered alternatives.

Examples of application of the method

Example 1.: Hospital resource management (Amaral, T. M., Costa, A. P. C., 2014)

An Emergency Department (ED) is considered the heart of a hospital and in many cities around the world, and especially in developing countries such as Brazil, it is very often the sole source of medical care. Making decisions about hospital resource management is not a trivial activity and incorrect decision-making can have serious consequences on the quality of health care services provided to the community. The application of the PROMETHEE II method is to support decision-making and resource management in an ED. Multiple Criteria Decision Analysis (MCDA) is especially useful in systems in which decision-making is complex and involves different considerations. PROMETHEE II was chosen for this study because its outranking approach is considered appropriate for the decision context of hospital services. This method was tested and validated with experimental data from a Brazilian public hospital. The ranking showed the best alternatives to be implemented to improve the throughput of patients in the “Blue Room”. Six months after implementing the best alternatives, the waiting time during periods of overcrowding had been reduced by around 70%. The PROMETHEE II method proved to be a rational tool to support the Decision Maker (DM) to choose the best alternative to solve bottlenecks related to overcrowding in an ED. Improving decision-making in hospital departments means taking actions to increase the throughput of patients and reducing the number of patients-in-process. (Amaral, T. M., Costa, A. P. C., 2014)

Example 2.: Sustainable management of municipal solid waste in Morocco: Application of PROMETHEE method for choosing the optimal management scheme (Makan, A. and Mountadar, M., 2013)

In this paper, alternate schemes are examined and analyzed aiming at the improvement of MSW management in small urban municipalities in Morocco. These schemes are estimated by developing and applying the PROMETHEE method consisting in a multi-criteria analysis of the parameters and constraints bound to the financial, technical, environmental and social-institutional aspects. Ten alternate management schemes were coopered and ranked according to their performance and their efficiency. The obtained results will certainly help the decision-makers to make a decision for the best management scheme that hold in account particularities of every region, commune or municipality in Morocco.

Example 3.: Facility Location Selection using PROMETHEE II Method (Athawale, V. M., Chakraborty, S. 2010)
Selecting a location for a new organization or expansion of an existing facility is of vital importance to a decision maker. The cost associated with acquiring the land and facility construction makes the facility location a long-term investment decision. The best location is that which results in higher economic benefits through increased productivity and good distribution network. Selecting the proper facility location from a given set of alternatives is a difficult task, as many potential quantitative criteria are to be considered. This paper solves a real time facility location selection problem using PROMETHEE II method

which is an effective multi-criteria decision-making (MCDM) tool often applied to deal with complex problems in the manufacturing environment.

Example 4.: Strategic decisions using the fuzzy PROMETHEE for IS outsourcing (Chen, Y. Wang, T., Wu, C. Y., 2011.)

Outsourcing has become a common strategy in the information system/information technology (IS/IT) field in recent years. Many organizations attempt to enhance their competitiveness, reduce costs, increase their focus on internal resources and core activities, and sustain competitive advantage by IS/IT outsourcing. Selection of appropriate outsourcing partners is an extremely important goal for organizations. This study presents the fuzzy Preference Ranking Organization Method for Enrichment Evaluation (fuzzy PROMETHEE) to evaluate four potential suppliers using seven criteria and four decision-makers using a realistic case study. Rankings results provide a reference that assists decision-makers or organizations seeking to improve the efficiency of the IS/IT outsourcing decision processes.

6 Advantages & Disadvantages of different economic approaches

The following synoptic table includes specific advantages and disadvantages of the aforementioned assessment approaches. It also contains short description of the procedure and the scope respectively the applicability.

Table 10: Advantages and disadvantages of the assessment methods

Approach	Description	Strengths	Weaknesses	Scope (i.e. more applicable in specific industry, CI etc.)
CBA	Comparison of costs and benefits in monetary values regarding different project alternatives	• Monetarization of input parameters → clear and transparent comparison criterion for decision makers • Gathering of local and global effects • Due to the clear assignment of costs and benefits it is a transparent procedure → easier understanding and acceptance	• Monetarization of input parameters → especially intangible impacts are sometimes difficult to assess with a monetary value→ subjective assessment possible • Effects of compensation • NPV considers "only" the set of alternatives, not applicable to discover the most appropriate option overall • Defined discount rate of costs and benefits have significant can Influence on results	• Commonly used method in most infrastructure projects, especially in transport related projects (e.g. modified approach in "Bundesverkehrs wegeplan" in Germany
CEA	Economic Analysis comparing costs in monetary terms with effects in qualitative terms of different alternatives	• Useful alternative to CBA in areas where benefits can-not be quantified monetarily to compare alternative adaptation options with a view to identifying the option which can reach a well-defined objective in the most cost-effective way. • It is particularly useful where there is a need for the analysis of benefits	• CEA is less suitable for complex or cross-sectoral risks • It can be often be difficult to identify a single common metric for analysis, because there are many types of risks across and even between sectors. • CEA tends to focus on technical options, because these can be easily assessed in terms of costs and benefits	• Most useful for short-term assessment, for market and non-market sectors. It is most relevant where there is a clear headline indicator and a dominant impact • It is also most appropriate where climate uncertainty is low, and good data exists for

		in non-monetary terms, notably in areas that are difficult to value, such as ecosystems or health.	(effectiveness). However, adaptation is now seen as a process as well as an outcome, and capacity building and non-technical (soft) options are considered an important and early priority. Such non-technical options do not lend themselves easily to the quantitative analysis in CEA, thus they tend to be given lower priorities (or omitted).	major cost/benefit components. • It is a useful tool for consideration of low and no regret option appraisal (short-term), especially for non-market sectors, and as a potential decision support tool as part of an iterative risk management framework.
MA	Linear Economic Analysis measuring the holistic impacts to the all (or certain) economic sectors of a region/country. Mainly in monetary terms	• the ability to reflect the economic interdependencies within a regional (or national) economy in detail for de-riving higher order effects, and partly on its simplicity • The basic production relations of an I-O model are comprehensive with respect to all in-puts, not just primary factors (capital and labor), so these models are especially useful in evaluating re-source-use implications of economic trends and policies	• Linearity • rigid structure with respect to input and import substitutions • lack of explicit resource constraints • lack of responses to price changes • the inability to analyse price and quantity impacts simultaneously	• CIs included in Council Directive 2008/114/EC (for methodologies IIM & DIIM) • Applicability for evaluating macroeconomic impacts in region-al/national level of a sector disruption
MCA	MCDA is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach falls	• it is open and explicit • the choice of objectives and criteria that any decision making group may make	• MCDA is not considering public expense efficiency at all.	• MCDA allows decision makers to include a full range of social, environmental, technical, economic, and

	short, especially where significant environmental and social impacts cannot be assigned monetary values. This method is generally used at the end of a process that clears up the different options	are open to analysis and to change if they are felt to be inappropriate • scores and weights, when used, are also explicit and are developed according to established techniques. They can also be cross-referenced to other sources of information on relative values, and amended if necessary		financial criteria

7 Suggested methods within EU-CIRCLE

The following descriptions are related to the question how cost effectiveness approach is foreseen within the case studies. At the date this report is delivered not each case study are at a state to describe exactly how to use the aforementioned methodologies. So the below mentioned descriptions can be considered as a prospect for the implementation of the cost effectiveness approach.

Case study 1 (Southern France):

Case study 1 will analyse the impacts of forest fires on electricity networks and motorways in South-East of France. The impacts of CH (forest fire, smoke) are not limited to the direct damages on CI assets. They encompass a wide range of impacts from voluntary time-limited service disruption (in order to allow rescue service intervention, people protection) or unforeseen service disruption which will cause indirect impacts (to people, services and other infrastructures served by the CI) and broader socio-economic impacts.

The direct impacts on CI assets can be estimated using cost estimates of replacing the damaged asset. It seems possible to make some cost-benefit analysis, comparing direct damages cost with adaptation options cost.

These indirect impacts are not necessarily measured in monetary units, but can be measured in physical units (e.g. number of hours of service disruption) or using cost proxies (externalities). The implication of CI operators in the preparation of the case study shows that perspective is different between operators. In particular, the indirect impacts to be considered are much broader with the electricity network operators than the highway operator. Therefore, a method that allows non-monetary analysis and putting different weights to reflect different priorities is preferred (e.g. MCA) for these indirect impacts.

The work on the case study is still under preparation at the time this deliverable is written, therefore the methodology and data used for case study 1 is further detailed in D6.3 Case Study 1 FR - Evaluation report.

Case Study 3 (Torbay-UK)

The climate –related hazards for the Torbay Case Study involve flooding (pluvial, coastal, sea surges), where three urban areas (Torquay, Paignton and Brixham) are affected. The impacts involve multiple stakeholders: water and electricity operators, transport operators (trains mainly), commerce, services (public and private), and businesses (especially touristic) with different priorities and interests.

Consequently, in order to evaluate the impact to the Torbay Case Study and develop adaptation strategies, these multiple stakeholders should be involved in the decision making, so as to maximise the mutual benefit to all parties involved and manage risk effectively. Therefore, in this case, we suggest that MCDA would be the most appropriate approach, possibly including also AHP for estimating the weights.

Currently, the infrastructure data (electricity substation, pumping station, road, rail, water treatment plant, hospital, flood defence,) have been collected. The assessment will include the maintenance and repairment cost of CIs and properties, losses or benefits to local business (particularly for tourism), the service disruptions and their cascading effects, health impact and the risk of life.

A stakeholder engagement workshop will be organized (October-November 2017) to gather inputs from operators of energy, water supply, waste water, rail network, roads, health service, environment agency, and city council for developing sustainable solutions for protecting the CI assets and services. The outcome from the workshop will feed into the cost-effectiveness analysis method developed in D4.7 for prioritizing the adaptation measures.

Case Study 4: (Bangladesh)

Khulna in Bangladesh is an interior coastal city and is a growing regional hub with a dense historic experience of tropical cyclones, a persistent urban drainage problem and a projected storm surge risk. With

a population of 1.4 million projected to reach 2.9 million by 2030, it is a site of current infrastructural development, rural to urban migration.

Another dimension to CI development considered under case study 4 is the experience of the water and agriculture sector with 'polderisation', a technique of embankment enclosure. Cyclones are known to severely impact the agricultural sector, with inundated land often requiring two years for the resumption of cultivation and farmers seeking alternatives in urban areas. Protecting croplands from flood inundation and tidal surges in this way has had several unintended consequences, for example waterlogging and river siltation thereby identifying some unique damage curves applicable within the Khulna context.

The wider industrial economy around Khulna is also important to consider, alongside the observation that a lot of new infrastructure is presently being assembled. The CI landscape of Khulna presents a complex array of built structures, organisations, relationships and performances, some of which are established and others that are still in their formative stage. In this instance, a cyclonic storm could knock out electricity distribution and the road transport links supporting Khulna's health, drainage and sanitation maintenance regimes, exacerbating the impact of waterborne illness and delimiting the operations of health services. Hence the cycle of impacts of cyclones (due to climate change) extends to a wider cascading socio economic level. This works well with the contributions that this case study makes towards the CIRP development that the EU-CIRCLE will deliver, based on scenarios and consequent CI performance which will allow operators and decision-makers to develop cost effective by context relevant appropriate adaptive responses not just to the direct impacts but cascading socio economic impacts and express benefits and costs in visually immediate, policy relevant terms.

Case Study 5 (Dresden-Germany):

The city region Dresden suffered several times in the past from severe river floods. Since the devastating flood in 2002, numerous adaptation measures (procedural, constructive, management etc.) measures have been implemented and the preparedness increased.

However, the focus was always on the water bodies on 1st order and on river floods. In recent years, it became obvious, that smaller rivers (2nd order water bodies) in connection with flash floods bear locally a high risk to infrastructures. Taking into account the climate change and city development it is planned, to analyse and evaluate adaptation option for specific infrastructures (sewage, drinking water, electricity, transport). At the current stage of case study preparation, we assume that rather straightforward assessment approaches are sufficient, such as scoring or MAUT in order to minimise data requirements.

8 Conclusion

The previous sections are a synoptic report of the main assessment approaches for each kind of project with important investment decisions. Especially infrastructure projects which aim to enhance the resilience of CIs are in the scope of EU-CIRCLE. For this group of infrastructure projects D4.7 investigated the applicability of the different assessments methods.

Regarding the case studies (to be conducted in the near future) and taking into consideration the until now collected data we could say that both MCDA and partially CBA seem to be the most appropriate methodologies. Additionally, parts of other methodologies (IIM, SAM and Economic Resilience Methods) could also be useful depending on available data and operators requirements. Due to D4.7's high interconnection with other Tasks and Deliverables, an extended version of this deliverable will be produced in near future, no further than M32. In that version, it could be feasible to come up with a consolidated procedure on how CI operators can better choose a method or parts of methods according to certain, classified and weighting criteria based on impact assessment (T3.4 and D3.3), adaptation to climate hazards (T4.4 and D4.6) and operators preferences and needs.

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