Chapter 6:
Methods for a joint consideration of indicators

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1. General considerations

2. Methods for building aggregated or composite indicators

3. Joint consideration with multi criteria methods

4. General evaluation of joint consideration methods

5. Joint consideration of indicators in practice

6. Conclusions

Factors affecting joint consideration of indicators

- Important factors affecting joint consideration of indicators are
  - ➔ the level of decision making (plans, programmes, projects)
  - ➔ the socio-economic context (information availability, level of development, prevailing technical expertise, …)
  - ➔ the type of decision making process (more or less akin to rational models and with more or less public participation)
  - ➔ the quest for sustainability (i.a. trade-offs between the three dimensions, …)

Issues related to joint consideration of indicators

Table 39: Comparison of three types of joint considerations of indicators.

	Selected representative indicators	Indicators aggregated within impact chains	Indicators aggregated across impact chains
Who is doing the subjective considerations	Decision-makers	⇒	Experts
Number of subjective considerations included	Fewer	⇒	More
Uncertainty levels	Lower	⇒	Higher
Types of uncertainties	Fewer	⇒	More
Transparency	Higher	⇒	Lower
Number of indicators	Many	⇒	Few
Information value	? [1]	? [1]	? [1]

[1] The question marks in the last row signalises that it is not determined which indicators represents the best information value for decision-makers.

General considerations

Table 40: Pros and cons of use of composite indicators in transport.

Pros	Cons
• Can summarise complex or multi-dimensional issues in view of supporting decision-makers. • Easier to interpret than trying to find a trend in many separate indicator • Facilitate the task of reflect complex issues in a comparative exercise. • Can assess evolution in environmental impacts on complex issues. • Reduce the size of a set of indicators or include more information within the existing size limit. • Facilitate to place issues of environmental performance and progress at the centre of the policy arena. • Facilitate communication with general public (i.e. citizens, media, etc.) and promote accountability.	• May send misleading policy messages if they are poorly constructed or misinterpreted. • May invite simplistic policy conclusions. • May be misused, e.g., to support a desired policy, if the construction process is not transparent and lacks sound statistical or conceptual principles. • The selection of indicators and weights could be the target of political challenge. • May disguise serious failings in some dimensions and increase the difficulty of identifying proper remedial action. • May lead to inappropriate policies if dimensions of performance that are difficult to measure are ignored.

General considerations

Tasks related to joint consideration of indicators

- Decide which impacts are relevant and should be assessed (scoping)
  - ➔ have enough information about project and affected area;
  - ➔ understand relevant legislation and implications;
  - ➔ have a good understanding of the decision-making process.
- Select which aspects or which effects within impact chains should be represented by the indicator or included in the aggregated indicator
- Measure the magnitude of associated impacts and effects
- Determine the significance of indicators within or between impact chains
  - include expert judgment, dialogue with stakeholders, reference to legislation and regulations, risk assessment, …

General considerations

Tasks related to joint consideration of indicators

- Weights typically have a great impact on the results of an aggregation
  - ➔ weighting models need to be made explicit and transparent!
- Whenever indicators, which are to be aggregated, are incommensurable with each other and/or have different measurement units, it is necessary to bring these indicators to the same scale
  - ➔ normalization is necessary!

General considerations

Tasks related to joint consideration of indicators

Table 41: Normalization methods according to Nardo et al. (2005).

Method	Equation
Ranking	$I_{qc}^{t} = Rank(x_{qc}^{t})$
Standardisation (or z-scores)	$I^{t}_{qc} = \frac{x_{qc}^{t} - x_{qc=\bar{c}}}{\sigma_{qc=\bar{c}}^{t}}$
Re-scaling	$I_{qc}^{t} = \frac{x_{qc}^{t} - \min_c(x_q^{t_0})}{\max_c(x_q^{t_0}) - \min_c(x_q^{t_0})}$
Distance to a reference	$I_{qc}^{t} = \frac{x_{qc}^{t}}{x_{qc=\bar{c}}^{t_0}} \; or I_{qc}^{t} = \frac{x_{qc}^{t} - x_{qc=\bar{c}}^{t_0}}{x_{qc=\bar{c}}^{t_0}}$
Categorical scales	$I_{qc}^{t} = \begin{cases} 25 \text{ if } x_{qc}^{t} \in \{p^{25th}\} \text{percentile} \\ 50 \text{ if } x_{qc}^{t} \in \{p^{50th} - p^{25th}\} \text{percentile} \\ 75 \text{ if } x_{qc}^{t} \in \{p^{75th} - p^{50th}\} \text{percentile} \\ 100 \text{ if } x_{qc}^{t} \in \{p^{100th} - p^{75th}\} \text{percentile} \end{cases}$
Indicators above or below the mean	$I_{qc}^{t} = \begin{cases} 1 \text{ if } w > (1+p) \\ 0 \text{ if } (1-p) \leq w \leq (1+p) \\ -1 \text{ if } w < (1+p) \end{cases}$ Where $w = x_{qc}^{t} / x_{qc=\bar{c}}^{t_0}$
Cyclical indicators (OECD)	$I_{qc}^{t} = \frac{x_{qc}^{t} - E_t(x_{qc}^{t})}{E_t(\lvert x_{qc}^{t} - E(x_{qc}^{t}) \rvert)}$
Balance of opinions (EC)	$I_{qc}^{t} = \frac{100}{N_e} \sum_{e}^{N_e} \text{sgn}_e(x_{qc}^{t} - x_{qc}^{t-1})$
Percentage of annual differences over consecutive years	$I_{qc}^{t} = \frac{x_{qc}^{t} - x_{qc}^{t-1}}{x_{qc}^{t}}$

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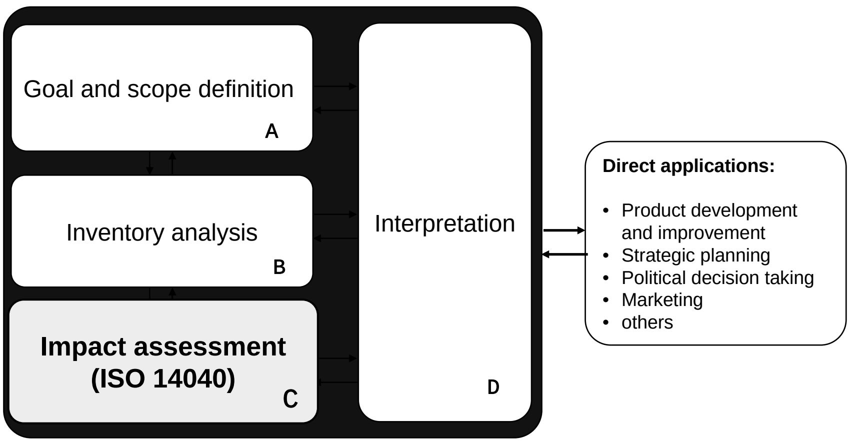
Methods for building aggregated indicators

Life cycle assessment

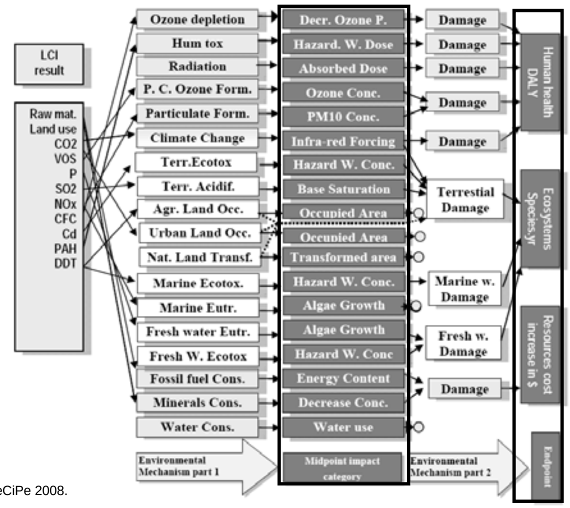
Phases of an LCA according to ISO 14040



Methods for building aggregated indicators

Life cycle assessment: The ReCiPe method

Integrating midpoint and enpoint approaches

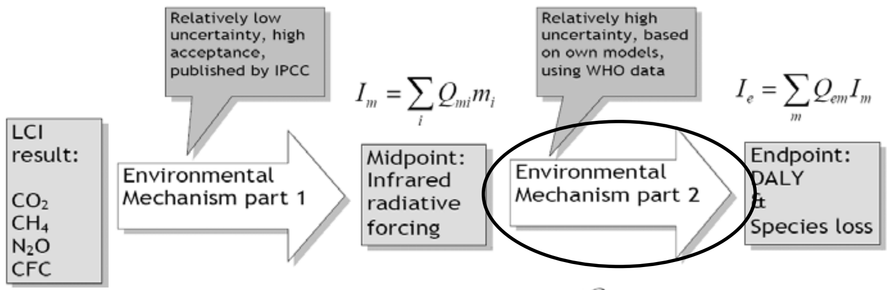


Goedkoop et al. (2009) ReCiPe 2008.

Methods for building aggregated indicators

Life cycle assessment: The ReCiPe method

Example of a harmonised midpoint-endpoint model: climate change



Q =characterisation factor

m_i = magnitude of intervention (e.g. CO_2 mass released to air)

Goedkoop et al. (2009) ReCiPe 2008.

Methods for building aggregated indicators

Life cycle assessment: The ReCiPe method

The three perspectives according to cultural theory (Thompson, 1990)

- **Individualist**: based on short-term interest, impact types that are undisputed, technological optimism as regards human adaptation
- **Hierarchist**: based on most common policy principles with regard to time-frame and other issues
- **Egalitarian**: most precautionary perspective, takes into account longest time-frame, impact types that are not fully established but for which some indication is available

Methods for building aggregated indicators

Life cycle assessment: The ReCiPe method

Quantitative connections between midpoint and endpoint categories

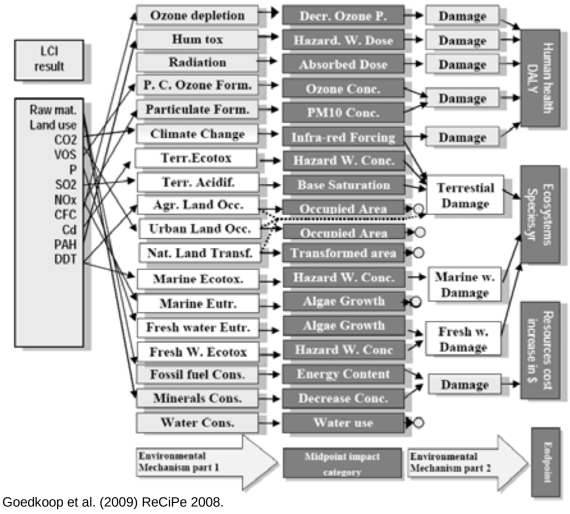
Midpoint impact category		Endpoint impact category*		
abbr.	Unit	HH (yr)	ED (yr)	RC ($/yr)
CC	kg (CO_2 to air)[10]	1.19×10^{-06}† (I) 1.40×10^{-06} (H) 3.51×10^{-06} (E)	$8.73\text{x}10^{-6}$ (I+H) $18.8\text{x}10^{-6}$ (E)	0

Aspect	Individualist	Hierarchist	Egalitarian
Dispersal of species	yes	yes	no
Temperature factor (°C.yr/kg CO_2)	1.064×10^{-13}	1.064×10^{-13}	1.064×10^{-13}
Damage factor (1/°C)	$75\text{x}10^{6}$	$75\text{x}10^{6}$	$177\text{x}10^{6}$
Characterisation factor (yr/kg CO_2)	$8.73\text{x}10^{-6}$	$8.73\text{x}10^{-6}$	$18.8\text{x}10^{-6}$

Goedkoop et al. (2009) ReCiPe 2008.

Life cycle assessment: The ReCiPe method

From endpoint indicators to an aggregated indicator



Normalisation
→relate to European reference values

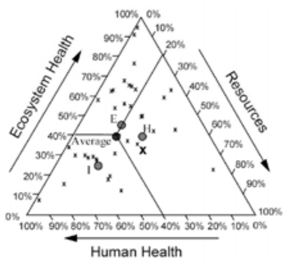
Aggregated indicator

Weighting

Goedkoop et al. (2009) ReCiPe 2008.

Life cycle assessment: The ReCiPe method

	Average	Individualist (n=10)	Egalitarian (n=14)	Hierarchist (n=5)
Ecosystem Quality	40%	25%	50%	40%
Human Health	40%	55%	30%	30%
Resources	20%	20%	20%	30%



Goedkoop and Spriensma (2001)The Eco-indicator 99: A damage oriented method for life cycle impact assessment. PRé Consultants.

Methods for building aggregated indicators

Life cycle assessment: The Ecological Scarcity Method

Multiplication of pollutant load or resource consumption with the Eco-Factor

$$Eco-Factor = \underbrace{K}_{\substack{\text{Characterisation} \\ \text{(optional)}}} \cdot \underbrace{\frac{1[EP]}{F_n}}_{\text{Normalization}} \cdot \underbrace{\left(\frac{F}{F_k}\right)^2}_{\text{Weighting}} \cdot \underbrace{c}_{\text{Constant}} \quad \text{[eq. 12]}$$

With:

- K = Characterization factor of a pollutant or of a resource
- F_n = Normalization flow: current annual flow, presently with Switzerland as system boundary
- F = Current flow: current annual flow in the reference area
- F_k = Critical flow: critical annual flow in the reference area
- c = Constant (10^{12}/year): serves to obtain readily presentable numerical quantities
- EP = Eco-point: the unit of environmental impact assessed

"Flow" refers to the load of a pollutant, the quantity of a resource consumed, or the level of an environmental impact characterized.

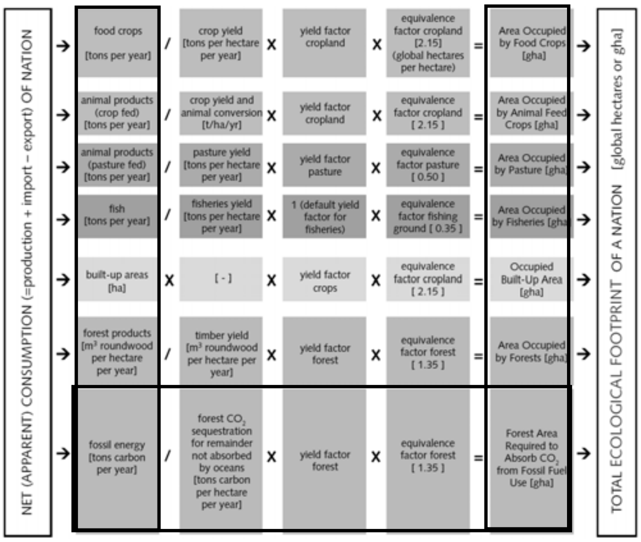
Factors affecting joint consideration

Life Cycle Assessment

- ☺ LCA is a sophisticated, well established approach, which allows to account for resource consumption as well as environmental impacts from a life cycle perspective
- ☹ The different impact assessment methods are not easily understandeable by non-experts and may provide contradicting results;
- ☹ ReCiPe does not (yet) consider all relevant connections between intervention, midpoint and endpoint indicators (e.g. between ozone depletion and ecosystems diversity);
- ☹ Indicators such as erosion, light, noise, salination (ReCiPe: midpoint) and damage to the man-made environment (ReCiPe: endpoint) are not yet considered.

Methods for building aggregated indicators

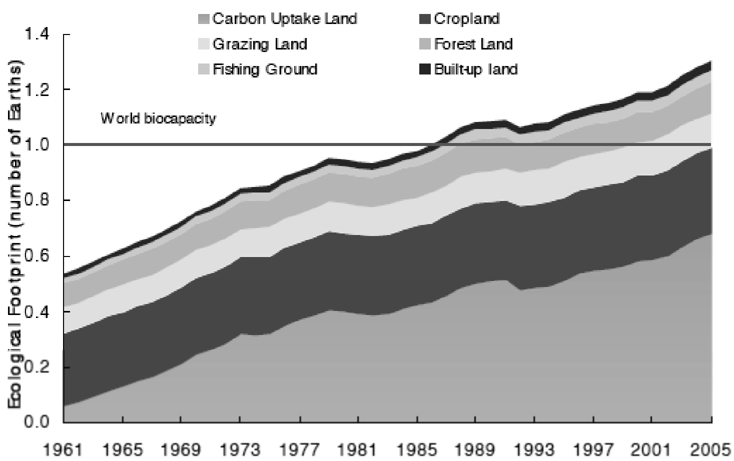
Ecological Footprint



Federal Statistical Office, 2006, Switzerland's Ecological Footprint – A contribution to the sustainability debate, Neuchâtel (Switzerland).

Methods for building aggregated indicators

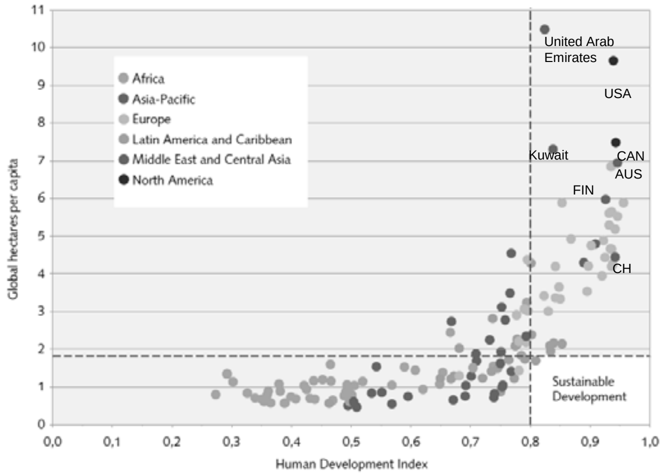
Ecological Footprint



Federal Statistical Office, 2006, Switzerland's Ecological Footprint – A contribution to the sustainability debate, Neuchâtel (Switzerland).

Methods for building aggregated indicators

Ecological Footprint



Federal Statistical Office, 2006, Switzerland's Ecological Footprint – A contribution to the sustainability debate, Neuchâtel (Switzerland).

Factors affecting joint consideration

Ecological Footprint

☺ Ecological Footprint is a powerful tool to make people aware of resources consumption

☹ Biocapacities of different kinds are merged, which makes their additivity questionable

- ➔ the forest area required to absorb CO_2 does not represent an actual land surface easily comparable to the earth surface;
- ➔ the forest area required to absorb CO_2 corresponds to a non-reversible use of land (the area cannot be used for carbon-uptake in the future)

☹ A low number of impacts is taken into account

- ➔ only 3 chains of causalities presented in chapter 2 (loss of natural habitat due to land take, non renewable resources use, greenhouse effect).

Methods for building aggregated indicators

Material Intensity per Service Unit (MIPS)

Material intensities for transport services

material	specification	Material intensity [t/t] / Materialintensität [t/t] abiotic material	biotic material	water	air	moved soil	
Transport / Transport		Material intensity [g/tkm] / Materialintensität [g/tkm] (only transport)					
sea going vessels Seeschiffe	all alle	6.00		52.0	10.000		Germany
	tanker Tanker	4.00		31.0	5.000		Germany
	container vessel Containerschiff	9.00		80.0	17.000		Germany
	cargo boat Frachtschiff	10.00		90.0	19.000		Germany
canal boats Binnenschiffe	all alle	24.00		160.0	35.000		Germany
	vessel Gütermotorschiff	25.00		163.0	37.000		Germany
	push boat Schub-Gütermotorschiffe	20.00		130.0	29.000		Germany
	four lighter barge train 4er Schubverband	19.00		130.0	20.000		Germany
cargo trains Frachtzüge	all German trains alle (DB)	77.00		3568.0	34.000		Germany
	diesel traction Dieseltraktion	55.00		149.0	56.000		Germany
	electric traction Elektrotraktion	83.00		4365.0	29.000		Germany
truck transport of cargo Straßengüterverkehr	all alle	218.00		1910.0	209.000		Germany
	lorry 2,8 t Lkw < 2,8 t	1,336.00		11630.0	1331.000		Germany
	all lorries 2,8 t alle LKW 2,8 t	450.00		4124.0	144.000		Germany
	articulated lorry Lastzüge 8t	107.00		927.0	102.000		Germany
	articulated vehicle Sattelzüge	89.00		731.0	100.000		Germany

http://www.wupperinst.org/uploads/tx_wibeitrag/MIT_v2.pdf

Factors affecting joint consideration

Material intensity per service unit (MIPS)

☺ MIPS is a simple and straightforward method

- ➔ all material inputs are accounted for by with mass units (summed up without any weighting)

☹ The MIPS method does not consider environmental impacts (although sometimes suggested);

☹ Even as a resource indicator the MIPS method might be misleading, because

- ➔ it does not consider qualititative differences between the different resources (e.g. their geophysical availability);
- ➔ it might be dominated by the most common or heaviests resources (e.g. water consumption).

General considerations

Economic indicators

☺ External cost valuation allows to take into account the environmental impacts of a human action in the assessment of its costs and advantages.

➔ Existing methods are to be considered complementary because they focus on different cost components

(1) the observation of real behaviours (revealed preferences);

(2) surveys revealing stated behaviours in hypothetical situations (stated preferences);

(3) a first systematic assessment of the impact chain involved and of the costs of each impact (damage oriented methods).

☹ Monetary methods for evaluating environmental damage cannot be expected to produce definitive, indisputable values, i.a. because the ways of discounting the future are very diverse.

Joint consideration with multi criteria methods

Multi criteria decision analysis (MCDA) methods

Table 44: Typical characteristics of MCDA methods.

	Characteristics	Examples
Discrete methods		
Single synthesizing criterion methods	- convert impacts concerning the different criteria into one criterion or attribute; - are based on strong assumptions, i.a. the existence of utility functions and additivity.	- MAUT - AHP - Evamix
Outranking methods	- are based on less 'strong' assumptions than single criterion methods; - encourage interaction between model and decision maker by avoiding complete ranking being identified too early; - do not so much aim at identifying an optimal solution but rather at facilitating the identification of compromise solutions in a transparent and fair way.	- ELECTRE III - PROMETHEE - Regime - NAIADE
Continuous methods		
Programming methods	- do not choose from a finite number of alternatives, but the alternatives are generated during the solution process on the basis of a mathematical model formulation.	- MOP - GP

Joint consideration with multi criteria methods

Discrete MCDA methods

- Typical problem**:** Rank a finite number of decision alternatives, each of them being described in terms of different characteristics (attributes, criteria, objectives)

Table 46: Structure of a typical decision matrix (Wang and Triantaphyllou, 2008).

Alternatives	Criteria			
	C_1	C_2	…	C_n
	(w_1)	(w_2)	…	(w_n)
A_1	a_{11}	a_{12}	…	a_{1n}
A_2	a_{21}	a_{22}	…	a_{2n}
…	…	…	…	…
A_m	a_{m1}	a_{m2}	…	a_{mn}

A_m: alternatives

C_n: criteria (represented by an indicator)

a_{mn}: performance values (value of the criterion Cn)

w_n: criteria weights

Joint consideration with multi criteria methods

Outranking methods: ELECTRE III

- Pairwise comparison of alternatives

  A_1 **S** A_2: A_1 outranks A_2

  p_i: preference threshold for criterion i

  q_i: indifference threshold for criterion i

- Possible relations between A_1 and A_2:

  A_1 **P** A_2: A_1 is strictly preferred over A_2 $\quad a_i(A_1) - a_i(A_2) \geq p_i$

  A_1 **Q** A_2: A_1 is weakly preferred over A_2 $\quad q_i \leq a_i(A_1) - a_i(A_2) \leq p_i$

  A_1 **I** A_2: A_1 and A_2 are indifferent $\quad a_i(A_1) - a_i(A_2) \leq q_i$

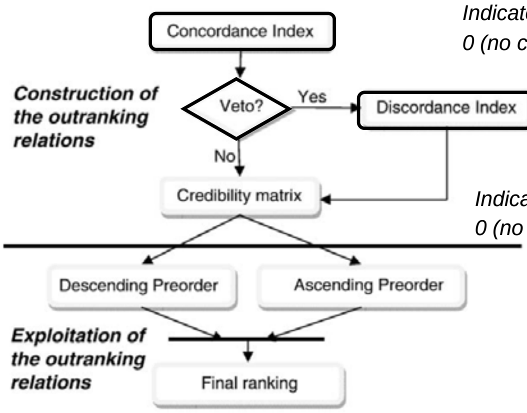
  S=(P,Q,I)

  A_1 **R** A_2: A_1 and A_2 are incomparable

Joint consideration with multi criteria methods

Outranking methods: ELECTRE III

ELECTRE III process flow



*Indicates the truthfulness of A_1 **S** A_2*
0 (no concordance) < $C(A_1,A_2)$ < 1 (concordance)

$$a_i(A_2) - a_i(A_1) \geq v_i$$

v_i: veto threshold for criterion i

*Indicates discordance with A_1 **S** A_2*
0 (no discordance) < $C(A_1,A_2)$ < 1 (discordance)

Giannoulis and Ishizaka (2010) Decision Support Systems 48 (3), 488-497.

Joint consideration with multi criteria methods

Outranking methods: ELECTRE III

Normalization and Weighting

- requirements for criteria (indicators)
  - completeness;
  - coherence;
  - non-redundancy.
- no normalisation;
- no explicit guidance given for the determination of weights, which reflect the subjective evaluation of the actors participating in the decision making process and are context dependent.

General evaluation

Performance of aggregated or composite indicators

Table 47: General evaluation of indicators assumed to measure overall environmental sustainability and resulting from the application of methods for building aggregate or composite indicators.

Indicator	Category: Representation (Validity, Reliability, Sensitivity)	Category: Operation (Measurability, Data Availability, Ethical concerns)	Category: Application (Transparency, Interpretability, Target relevance, Actionability)
Ecological Scarcity method (for Switzerland) ReCiPe (for Europe)	**medium/good**	**good**	**low/medium**
Ecological footprint	**low/medium**	**medium/good**	**low/medium**
MIPS	**low/medium**	**medium/good**	**low/medium**
Economic approaches (stated preferences) Economic approaches (revealed preferences) Economic approaches (damage oriented)	**medium/good**	**medium/good**	**medium**

x=poor; xx=limited; xxx=good; xxxx=excellent

General evaluation

MCDA methods

		MAUT	AHP	Evamix	Electre III	Regime	NAIADE	MOP/GP
Operational components of methods								
Criteria	Interdependence	Not allowed	Allowed	Not allowed	Not allowed	Not allowed	Not allowed	Not allowed
	Completeness	Allowed	Allowed	Allowed	Allowed	Allowed	Allowed	Required
	Non-linear preferences	Allowed	Not allowed	Not allowed	Not allowed	Not allowed	Allowed	Allowed for some variants
Weights	Transparency of process, type of weights	Cardinal weights assigned	Cardinal weights assigned	Ordinal weights assigned	Cardinal weights assigned	Ordinal weights assigned	No weights assigned	Weights assigned for some variants
	Meaning	Trade-offs	Importance	Importance	Importance	Importance	No weights	Importance
Solution finding procedure		Complete ranking	Complete ranking	Complete ranking	Non-dominated option/s calculated	Complete ranking	Non-dominated option/s calculated	Non-dominated option/s calculated
Applicability in user context								
Project constraints	Costs	Depending on the numbers of attributes, stakeholders involved, etc.	Depending on the numbers of attributes, stakeholders involved, etc.	Depending on the numbers of attributes, stakeholders involved, etc.	Depending on the numbers of attributes, stakeholders involved, etc.	Depending on the numbers of attributes, stakeholders involved, etc.	Depending on the numbers of attributes, stakeholders involved, etc.	Depending on the numbers of attributes, stakeholders involved, etc.
	Time	Depending on the numbers of attributed, stakeholders involved, etc.	Depending on the numbers of attributed, stakeholders involved, etc.	Depending on the numbers of attributed, stakeholders involved, etc.	Depending on the numbers of attributed, stakeholders involved, etc.	Depending on the numbers of attributed, stakeholders involved, etc.	Depending on the numbers of attributed, stakeholders involved, etc.	Depending on the numbers of attributes, stakeholders involved, etc.
Structure of problem solving process	Stakeholder participation	Necessary	Necessary	Supported	Supported	Supported	Necessary	Supported by a few variants
	Problems structuring	Via the construction of utility functions	Via the construction of suitable hierarchies	Via the construction of the evaluation matrix	Sometimes cumbersome	Vie the construction of the Regime vector	Via the construction of the evaluation matrix	Model based
	Tool for learning		Appropriate	Not appropriate			Appropriate	interactive MOP
	Transparency	High	High	High	Medium	Medium	High	Low
	Actors communication	Via the integration of stakeholders	Via the integration of stakeholders	Via the integration of stakeholders	Via the integration of stakeholders	Via the integration of stakeholders	Via the integration of stakeholders	Via the integration of stakeholders

From: de Montis et al. (2005)

General evaluation

MCDA methods

		MAUT	AHP	Evamix	Electre III	Regime	NAIADE	MOP/GP
Applicability for problem structure								
Indicator characteris-tics	Geographical scale	Different can be treated	Different can be treated	Different can be treated	Different can be treated	Different can be treated	Different can be treated	Different can be treated
	Micro-macro-link	Possible	Possible	Possible	Possible	Possible	Possible	Possible
	Societal/technical issues	Different issues are possible	Different issues are possible	Different issues are possible	Different issues are possible	Different issues are possible	Different issues are possible	Different issues are possible
	Methods combinations	Possible	Possible	Possible	Possible	Possible	Not possible	Possible
Data situation	Type of data	Qualitative and quantitative possible	Qualitative and quantitative possible	Qualitative and quantitative possible	Mainly quantitative	Qualitative and quantitative possible	Qualitative and quantitative possible	Mainly quantitative
	Risk/Uncertainties	Risky outcomes: probabilities, sensitivity analysis	Via sensitivity analysis	Via ordinal criteria only	Via thresholds		Via stochastic and fuzzy numbers	Via sensitivity analysis and fuzzy numbers
	Data processing amount	High	Medium	Low	High	Medium	Medium	Medium
	Non-substitutability	Not possible	Not possible	Not possible	possible	Not possible	Not possible	Possible via constraints or lexicographic ordering

Table 4. Summary of method comparison

From: de Montis et al. (2005)

General evaluation

Performance of MCDA methods

- Chosing an adequate MCDA method for a comparison of alternatives depends on the specific decision making context (decision tier, goal and scope, involved actors, available data, …);
- Nevertheless, some general recommendations for the selection of MCDA methods (in the context of sustainability) have been given, i.a.
  - for a complete ranking of the given alternatives: apply MAUT, AHP, Evamix, or Regime;
  - if working with different conflicting interest groups: apply NAIADE and AHP.
  - if thresholds and constraints are central for the problem under investigation: apply Electre III or GP/MOP.

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Conclusions

Methods for building aggregated or composite indicators

- A most critical element of the environmental assessment appears to be the determination of the significance of environmental impacts. Significance should be determined under consideration of i.a. expert judgement, dialogue with stakeholders and reference to legislation and regulations.
- Indicators become more uncertain, less transparent and leave more of the subjective value considerations in the hands of the experts as aggregation levels increase. Which aggregation level to chose will mainly be context dependent and situation driven.
- Each of the aggregation methods considered has its own profile regarding representation, operation and application performance, which has to be considered when chosing a method or interpreting its results.

Conclusions

Joint consideration with multi criteria methods

- For a consideration of strong sustainability issues and compliance with statutory regulations sophisticated outranking methods allowing to set thresholds and constraints such as ELECTRE III appear to be most suitable.
- The fear that the actors involved in the decision making process might perceive such sophisticated MCDA methods as 'black boxes' could lead to the use of (too) simple, straightforward methods.
- The largest potential for an application of MCDA methods in the context of sustainable development appears to lie in
  - the combination of multi-criteria algorithms with participatory techniques, guaranteeing mutual exchange of arguments and information, providing all participants with opportunities to add and challenge claims, and creating active understanding among them;
  - their integration into specific transport decision making contexts.

Thank you for your attention!

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