SCORE LCA

STUDY N° 2015-02

USE OF MULTICRITERIA ANALYSIS FOR AID-DECISION IN LCA

Executive summary

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SCORE**LCA** is an association that has been created to financially support collaborative research on LCA and related topics. It aims to promote and organize cooperation between companies, institutional and scientists in order to support the evolution of LCA methods and its practical implementation at European and international level.

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- ✓ The information and conclusions presented in this document were established on the basis of scientific and technical data and regulatory and normative framework in force at the date of the publication of documents.

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1 Introduction

The difficulty of decision-making within complex environment (whether for public policy orientation, territory development, strategic orientation for a company, or choice of solutions for design process) is a well-known situation for everyone faced with obligation to choose « the » solution among a set of possible solutions. In such situations, we are confronted to the following dilemma: either a simplification to facilitate decision-making by reducing multicriteria to monocriteria, but with a loss of information, or keeping completeness of information but resulting in more complexity with the risk of non-decision.

LCA is a calculation tool providing an environmental information that can be used in a variety of decision-making situations. To be intelligent, LCA results need to be multicriteria. So LCA provides a multicriteria information more to a decision-situation which is already complex. The stake is to deal with the multicriteria form of LCA results.

To solve this dilemna are mathematical methods for multicriteria analysis which aim is to define one or more optimal solution in the Pareto sense.

This study for ScoreLCA aims to explore the potential of multicriteria decision analysis methods (MCDA) for LCA in situation of decision-making including environmental aspects.

Furthermore, this study aims to propose a guide for LCA practionners and users for the choice of the most appropriate MCDA method within a given context.

The study includes three parts:

- The first part consists of a state of the art of MCDA methods relying on a scientific bibliography. It presents a set of seven methods that are representative of four differents classes of MCDA methods. Finally it proposes two MCDA methods (MACBETH and ELECTRE) that seem particularly well adapted to LCA context.
- The second part consists of a case study in which the two selected methods (MACBETH and ELECTRE) were implemented with LCA results of the comparison of electric vehicles vs combustion engine vehicles. This case study was completed with implementation of the method PRIOR that is a french weighting method dedicated to LCA results and is typical of the way LCA community usually pratices to deal with multicriteria analysis.
- The third part is a recommendation manual to help LCA practionners to select the most adapted MCDA method within their specific context.

2 State of the art of MCDA methods

Aid-decision is to guide a decision-maker that faces a problem where several alternatives are possible (solutions, actions, choices, scenarios, etc.). In order to choose the « best » one, consequences of each alternative should be determined to be able to compare them.

Many methods and tools were proposed for aid-decision in a multicriteria context. They are generally reffered to as MCDA method (multicriteria decision analysis). The state of the art presents an historical perspective of methodological developments relative to multicriteria analysis, as well as mathematical concepts underlying the different classes of MCDA methods.

Use of multicriteria analysis for aid-decision in LCA

MCDA methods can adress different problematics:

- Choosing : selection of the « best » alternative(s)
- Ranking : total or partial ordering of alternatives considering their respective qualities
- Sorting : affectation of alternatives to predefined categories

MCDA methods can be put in order under different classifications according criteria among which:

- Methods for optimization versus multicriteria analysis
- Methods permitting compensation between attributes or not
- Methods relying on aggregation operators or not
- Method AC (aggregation and comparison) versus method CA (comparison and aggregation)
- Etc.

Figure 1 below, adapted from (Seppälä et al., 2001), proposes a typology of MCDA methods. The methods cited in this figure are presented in details in the report of the study.

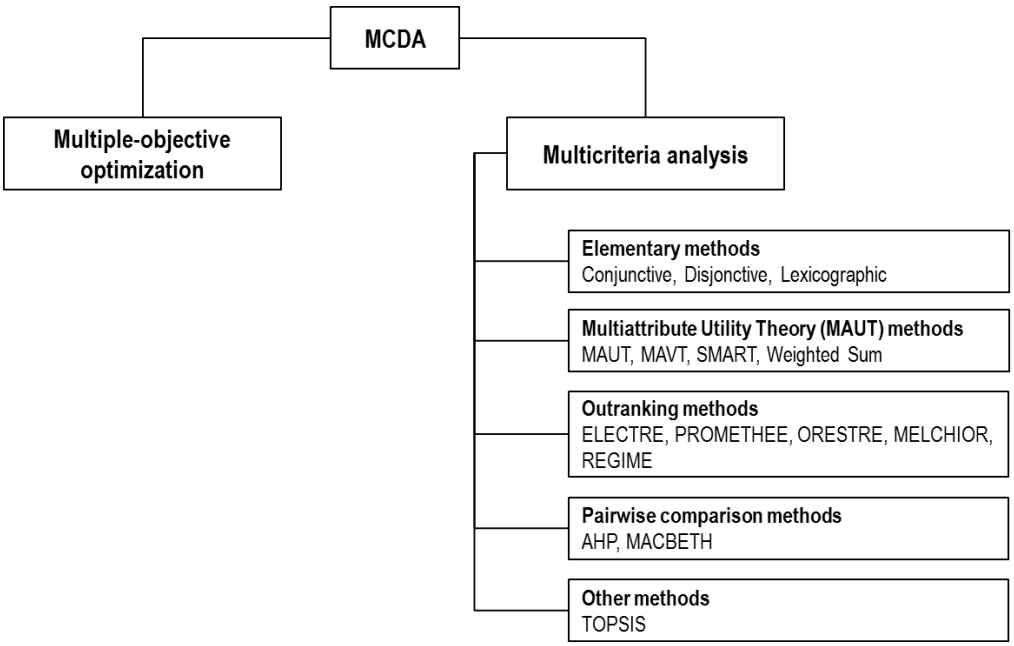


Figure 1. Typology of MCDA methods, adapted from (Seppälä et al., 2001)

It cannot be claimed that one MCDA method is better than others. The choice depends on the problematic under examination, available data, and forecasted results. The ideal method would be a method borrowing techniques to each class of MCDA methods presented above.

The state of the art carried out in this study inventories and compares the main MCDA methods as presented in figure 1. Table 1 gives a synthesis of this comparison according to several criteria.

MCDA methods / *Criteria*	MAUT	Weighted average	PROMETHEE	ELECTRE	AHP	MACBETH	TOPSIS
Uncertainty taken into account	Yes	Yes	Yes/No	Yes/No	Yes/No	No	Yes
Ease of implementation	Depends on agg. op.	Easy	Medium	Medium	Easy	Medium	Medium
Aggregation operator[1]	All	WA	WA	WA	WA	WA, CI	WA
Pairwise comparison	No	No	No	No	Yes	Yes	No
Compensation	Depends on agg. op.	Yes	Semi compensation	No	Yes	Yes	Yes
Software available	Yes	Yes	Yes	Yes	No	Yes	No
Quantity of information to retrieve	Depends on agg. op.	Medium	Medium	Medium	Important	Important	Medium
Separability required	Depends on agg. op.	Yes	No	No	Yes	Yes/No	No
Independence required	Depends on agg. op.	Yes	No	No	Yes	Yes/No	Yes
Calculation of utilities required	Yes	Yes/No	Yes	No	No	Yes	No
identification of parameters is integrated	Yes	No	No	No	Yes	Yes	No
Already tested for LCA	Yes	Yes	Yes	No	Yes	No	No
Mix of quanti/quali criteria	No	No	Yes	Yes	Yes	Yes	No
High heterogeneity is accepted	Depends on agg. op.	No	Yes	Yes	No	No	No
Richness of aggregation operator	Yes	No	No	No	No	CI	No
AC/CA[2]	AC	AC	CA	CA	AC	AC	AC
Aggregation of preferences	No	No	Yes	Yes	No	No	No
Aggregation of assessments	Yes	Yes	No	No	Yes	Yes	Yes

Tableau 1. Comparison of different MCDA methods

In conclusion, the keypoints to remember about MCDA methods are listed below:

- The aim of multicriteria analysis is to model the decision-behavior of a decision-maker (or a group of decision-makers) who is (are) facing a complex decision.
- To choose to optimize (ie. to indicate, in all circumstances, the best decision) comes down implicitly to adopt a monocriteria approach.
- Any multicriteria analysis process necessarily understands a stage of expression of decision-maker's preferences. So, the final solution given by MCDA not only depends on the implemented method but also on decision-maker's preferences.

[1] WA = weighted average. CI = Choquet integral.

[2] Operation order: AC = aggregation and comparison. CA = comparison and aggregation.

- Aggregation stage of any MCDA method embeds the question of compensation (and thus for LCA the question of compensation of one environmental impact by another one – or several others). Most of the MCDA methods can be considered as compensatory methods. By construction, outranking methods are « less compensatory » than methods with a single synthesis score.
- Multicriteria analysis should clearly identify and distinguish realities of first order (that can be measured objectively) from realities of second order (that can not be measured objectively and which value relies on subjectivity and consensus). Furthermore, a correctly designed aid-decision must consider realities of second order.
- Generally, the more the model integrates and models decision-behaviors, the more it is expensive to feed.
- To use the weighted sum as aggregation operator requires that the attributes (which are called environmental impact indicators in LCA) meet the conditions of independence[3] and separability[4].
- The quest for defining a universal and definitive table of priorization for environmental impacts seems to be an illusion. Such a table is unattainable because it can only be the translation of a system of values relative to a socio-political context and translating logics of different stakeholders about environmental stakes and relations between economy and ecosystems.

Finally, as a conclusion of the state of the art the recommendation is given to test two specific methods with a LCA case study : MACBETH (pairwise comparison method giving a single synthesis score, type AC) and ELECTRE (outranking method, type CA). It should be noted that MACBETH has never been tested for LCA.

3 Case study

3.1 Description of the case study

The two recommended methods from the state of the art, namely MACBETH and ELECTRE, have been implemented on a LCA case study. Furthermore, in order to complete the analysis, we implemented a third method, namely the PRIOR[5] method, that is perfectly representative of the usual practices of the LCA community when addressing the weighting stage in LCA.

The LCA case study[6] is a comparison of electric vehicles (EV) versus combustion engine vehicles (CEV) for five scenarios:

- EV used in France (EV-FR)

[3] Independence means that the score of an alternative on a criterion never is influenced by its score on another criterion.

[4] The criteria are separable if for each criterion i, the following property holds: if for the criterion i, the value a_i is preferred to the value b_i for every pair of alternatives (a, b) respectively having the scores a_i and b_i for i, and having the same values on any other criteria different from i, then a is preferred to b.

[5] Bio Intelligence Service. Projet PRIOR. Mise au point d'un outil de priorisation des enjeux environnementaux. Rapport, décembre 2005. Convention Ademe Eco-conception n°04 77 C 0072.

[6] The case study refers to and is documented in the following report available on the Internet :
Ademe, 2012. *« Élaboration selon les principes ACV des bilans énergétiques, des émissions de gaz à effet de serre et des autres impacts environnementaux induits par l'ensemble des filières de véhicules électriques et des véhicules thermiques, VP de segment B et VUL à l'horizon 2012 et 2020 »*. Report, Ginko 21 and PE International.

- EV used in Germany (EV-GE)
- EV used with an average European electricity mix (EV-EU27)
- Gasoline CEV
- Diesel CEV

For the purpose of the case study, the scope of the study has been reduced to five scenarios (as cited above) and seven indicators: climate change, acidification, eutrophication, cumulative energy demand, NOx emissions, radioactive wastes, and radioactive emissions (air). The results of the environmental impacts for each of the five scenarios are presented on table 2 below.

			Scenarios				
Indicators	**Abbreviation**	**Unit**	**EV-GE**	**EV-EU27**	**EV-FR**	**Gasoline CEV**	**Diesel CEV**
Climate change	CC	kg CO_2-eq	1,78E+04	1,49E+04	6,78E+03	2,69E+04	2,22E+04
Acidification	Ac	kg SO_2-eq	4,78E+01	7,03E+01	3,43E+01	4,15E+01	4,90E+01
Eutrophication	Eutro	kg P-eq	4,00E+00	4,27E+00	2,56E+00	3,75E+00	6,46E+00
Cumulative energy demand	CED	MJ	3,09E+05	2,99E+05	3,02E+05	4,11E+05	3,32E+05
Radioactive wastes	RW	kg	5,08E-02	6,25E-02	1,51E-01	1,27E-02	1,28E-02
Radioactive emissions (air)	RE	Bq I129-Eq	10,64E+08	12,8E+08	23,17E+08	7,94E+08	7,85E+08
NOx emissions	NOx	kg	2,34E+01	2,66E+01	1,41E+01	2,00E+01	3,48E+01

Tableau 2. Results of impact indicators used for the case study (extract from the LCA report referenced in note 6)

Twelve environmental experts from seven different organizations[7] participated in testing both MACBETH and ELECTRE. For the MACBETH method, two different methods of aggregation were tested, respectively the weighted average with Shapley index and Choquet integral (k-additive). For the ELECTRE method, the ELECTRE III method with the Simos method for the weighting of indicators was applied.

Otherwise, for the PRIOR method two different sets of normalization factors were used, respectively ILCD and ReCiPe.

Finally, a total of and 5 methods (from three classes of methods) were tested, from which multicriteria analysis results were compared.

3.2 Results

The figure 2 presents the synoptic of the whole results obtained from the case study with the implementation of the three methods MACBETH, ELECTRE, and PRIOR. All these results are presented and detailed in the final report. Only presented here are the final respective scores for the comparison of methods[8].

[7] *Different companies and the association ScoreLCA.*

[8] For the presentation of the results, expert's names have been anonymized with the following code : each organization (companies) is identified with a letter from A to G and each expert from these organizations (1 or 2 experts for each organization) is assigned with a number (1 or 2). Finally, experts are numbered from A1 to G2.

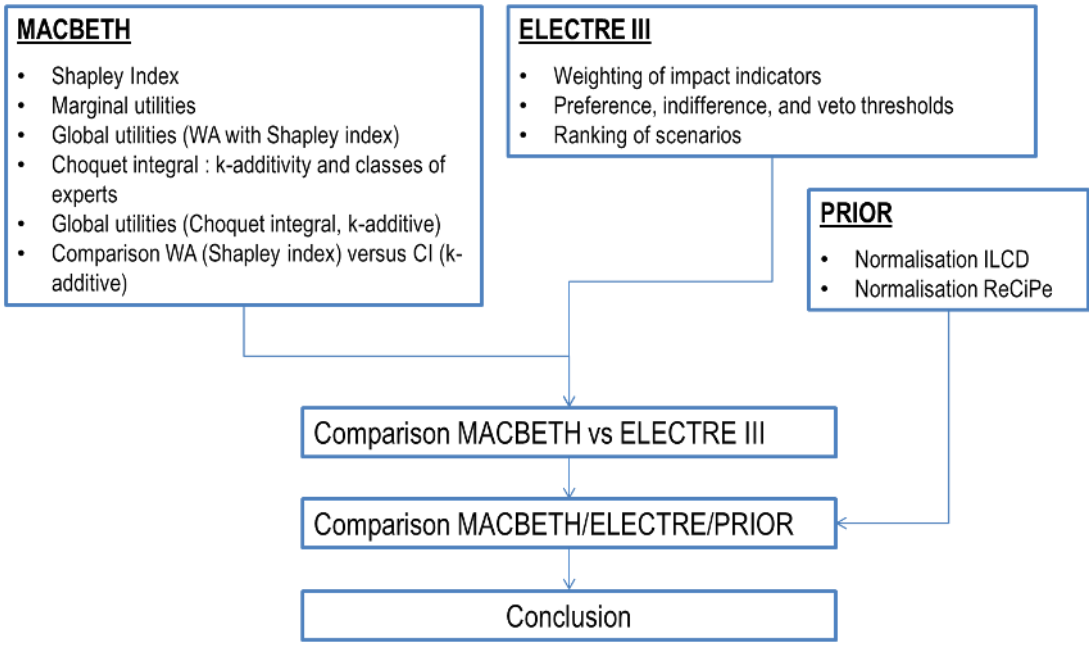


Figure 2. Synoptic of presentation of the whole results obtained with the case study

The table 3 presents the final scores obtained for each of the five vehicle scenarios with the MACBETH method (Choquet integral, k-additive).

Scénarios / *Experts*	EV-GE	EV-EU27	EV-FR	Gasoline CEV	Diesel CEV
F1	0,368689	0,210718	0,263979	0	5,28E-05
F2	0,367683	0,292482	0,324523	0,126186	0,0720442
E2	0,500165	0,444254	0	0,300566	0,159841
E1	0,483642	0,373161	0,293801	0,340709	0,24904
D2	0,642944	0,459913	0,97553	0,27547	0,401575
D1	0,363987	0,524919	0,905762	0,595174	0,191432
G2	0,457319	0,512912	0,861002	0,442842	0,337881
G1	0,417275	0,216375	0,580203	0,486585	0,534112
B1	0,619948	0,55744	0,899022	0,541752	0,336403
B2	0,42937	0,142641	0,427866	0,143171	0,213318
A1	0,087101	0,142831	0,871163	0,279131	0,000208

Tableau 3. Final scores for the five vehicle scenarios with the MACBETH method (Choquet integral). In green : the best scores ; in orange : the worse scores

With the MACBETH method (with Choquet integral, k-additive) the choices of the best scenario are equally distributed between the EV-GE scenario and the EV-FR scenario. The most of the worse solutions is assigned to the Diesel CEV scenario.

The figure 3 presents the results obtained with the PRIOR method according to two different sets of normalization values (ILCD and ReCiPe). Note that with PRIOR, by construction of the method, the system of weighting values is unique, and so final scores are independent from experts.

		EV-GE	EV-UE27	EV-FR	Gasoline CEV	Diesel CEV	Most contributing indicators (by order of importance)
ILCD	Score	19,98	21,74	28,53	20,17	19,77	1. *RE air* 2. *Energy* 3. *Climate change*
	%	*101%*	*110%*	*144%*	*102%*	*100%*	
	Rank	2	4	5	3	1	
ReCiPe	Score	11,39	11,79	11,17	13,27	12,79	1. *Energy* 2. *Climate change* 3. *RE air*
	%	*102%*	*106%*	*100%*	*119%*	*115%*	
	Rank	2	3	1	5	4	

Figure 3. Final scores obtained with the Prior method, respectively for the ILCD and ReCiPe normalisation set values

With the PRIOR method, with ILCD normalization, the Diesel CEV vehicle gets the best score (and the EV-FR scenario gets the worst), while with the ReCiPe normalization the EV-FR scenario gets the best. With PRIOR, for this example, the normalization values actually have more influence on the final score than the weighting values.

The table 4 below presents a comparison of the final ranking scores obtained with each method (only three of the five variants are presented here).

	Best scores or ranks			**Worse scores or ranks**		
	Macbeth CI k-add	**Electre III**	**Prior (ReCiPe)**	**Macbeth CI k-add**	**Electre III**	**Prior (ReCiPe)**
F2	EV-GE	EV-FR	EV-FR	Gas. CEV	EV-EU27, Dies. CEV	Gas. CEV
F1	EV-GE	EV-GE	EV-FR	Dies. CEV	EV-EU27	Gas. CEV
E2	EV-GE	Gas. CEV	EV-FR	EV-FR	EV-FR, EV-EU27	Gas. CEV
E1	EV-GE	Gas. CEV	EV-FR	Dies. CEV	EV-EU27	Gas. CEV
D2	EV-FR	EV-FR	EV-FR	Gas. CEV	Dies. CEV	Gas. CEV
D1	EV-FR	EV-FR	EV-FR	Dies. CEV	EV-EU27	Gas. CEV
G2	EV-FR	EV-FR	EV-FR	Dies. CEV	Gas. CEV	Gas. CEV
G1	EV-FR	Dies. CEV	EV-FR	EV-EU27	Gas. CEV	Gas. CEV
B1	EV-FR	EV-GE	EV-FR	Dies. CEV	EV-EU27	Gas. CEV
B2	EV-GE	Dies. CEV	EV-FR	EV-EU27	Gas. CEV	Gas. CEV
A1	EV-FR	EV-FR	EV-FR	Dies. CEV	Gas. CEV	Gas. CEV
C1	-	EV-GE	EV-FR	-	EV-EU27	Gas. CEV

Tableau 4. Comparison of the different final scores obtained with the three different methods Macbeth, Electre, and Prior (identical scores are marked in green, and totally different scores – 3 different vehicle scenarios – are marked in orange)

Considering the results obtained for the twelve experts:

- There is a convergence for the best choice for only four experts.
- For three experts, their choices are each time different according to the method.
- About the worse scenario, there is absolutely no convergence: no expert can appoint his worse scenario with three different methods.

3.3 Conclusion

The case study demonstrates that MCDA methods are totally well-adapted for interpretation of multicriteria LCA results. Nevertheless, the required resources and skills can vary a lot according to the selected method (resources for implementing Electre are less important than for implementing Macbeth).

The comparison of the three MCDA methods and their respective variants underlies the sensitivity of the results to the selected method. This point highlights the need for carrying out sensitivity analysis for each MCDA process. Note that this stage has not been done during this study but it is forecasted for all MCDA process (in the same way sensitivity analysis is a forecasted stage of LCA process).

4 Recommendation manual for LCA practionners

The recommendation manual first gives warnings about the principles of multicriteria analysis and what can be expected or not. As already mentioned, it cannot be expected an analysis model without any subjectivity, and a universal model will probably never exist.
The manual specifies criteria to be considered for choosing the MCDA method that could be the most appropriate given the context. Furthermore, these criteria are specified with regard to the specificities of LCA methodology.
The manual proposes general recommendations and a logical diagram for guiding the choice between MACBETH and ELECTRE.
Finally, the manual addresses different issues like the resources required to implement a multicriteria analysis, the case of multi-decision-makers within the same organization, and generalization of MCDA in a company for LCA and ecodesign issues.

4.1 Criteria to be considered for choosing a MCDA method

The criteria to be considered for choosing a MCDA method are listed below. These criteria are made explicit in the report.

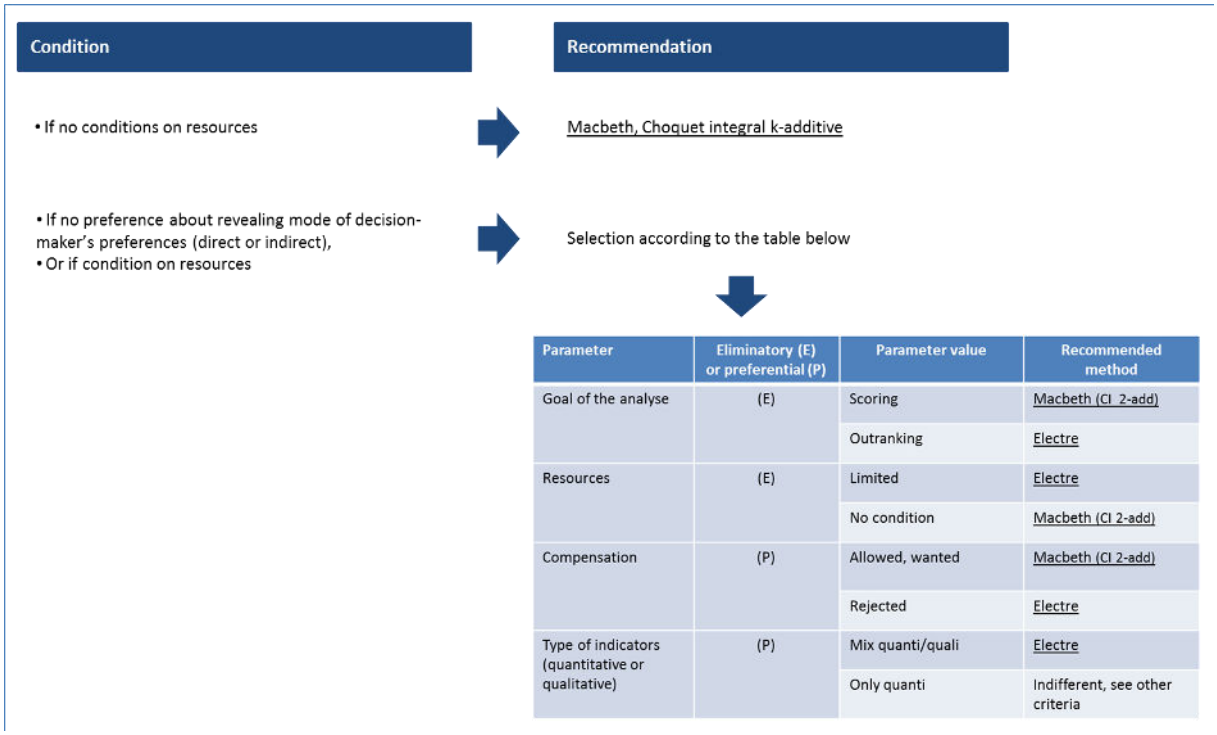
- Number of indicators (environmental impacts) and number of scenarios to be considered.
- Separability and independence of environmental impacts indicators.
- Acceptance or not for compensation.
- Aggregation operator.
- Development mode for parameters of the preference model: direct or indirect.
- Type of method : AC or CA
- Mix of quantitative and qualitative indicators.

4.2 General recommendations and logical diagram

It must be kept in mind that the choice of a MCDA method is highly dependent of the context. Thus, there is no best method but only most appropriate method. Nevertheless, coming from the case study and, beyond, from the experience of Armines with MCDA methods, three general recommendations can be formulated:

- Weighted sum methods (as PRIOR) as usually implemented in LCA are not appropriate to LCA (notably because of mathematical reasons) and must be avoided.
- It should be preferred methods with indirect revealing mode of decision-makers' preferences.
- The MACBETH method with Choquet integral 2-additive seems to be the best compromise between resources (costs) and performance (accuracy of the transcription of decision-maker's preferences). So, independently of the resources, this method should be preferred.

The figure 4 below is a logical diagram for guiding the choice between MACBETH and ELECTRE, the two recommended methods as being particularly well appropriate for LCA context.



Parameter	Eliminatory (E) or preferential (P)	Parameter value	Recommended method
Goal of the analyse	(E)	Scoring	Macbeth (CI 2-add)
		Outranking	Electre
Resources	(E)	Limited	Electre
		No condition	Macbeth (CI 2-add)
Compensation	(P)	Allowed, wanted	Macbeth (CI 2-add)
		Rejected	Electre
Type of indicators (quantitative or qualitative)	(P)	Mix quanti/quali	Electre
		Only quanti	Indifferent, see other criteria

Figure 4. Logic diagram for the selection of a MCDA method

5 Conclusion

The aim of this study was to explore the potential of use of MCDA methods for LCA issues. In fine the stake is to facilitate the interpretation of LCA results and the decision-making.

The main conclusions pointed out by this study are the following:

- Based on the state of the art, MACBETH and ELECTRE are the two recommended methods as being well-adapted to LCA methodology and offering a diversified panel of techniques for different contexts.
- Furthermore, the recommendation manual for LCA practionners and users gives recommendations for choosing between MACBETH or ELECTRE III when considering the context of a specific decision-making.
- The case study clearly shows the high sensibility of the scoring or ranking results with the MCDA method.
- The case study and the experience indicate that the MACBETH method with Choquet integral 2-additive is the best compromise between required resources (costs) and performance (accuracy of the transcription of decision-maker's preferences).
- The study challenges usual weighting practices by the LCA community and finally recommends not to use weighted sum for multicriteria analysis in LCA.

Finally, the case study demonstrates that MCDA methods are totally well-adapted for interpretation of multicriteria LCA results. Nevertheless, the required resources and skills can vary a lot according to the selected method.

More than identifying the best scenario, multicriteria analysis by revealing the decision-maker's preferences helps to justify the choice of one particular LCA scenario, and so can helps to justify the decision-making.