# Perspectives on Multi-criteria Decision Analysis and Life-Cycle Assessment

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**Abstract** This chapter covers the combined use of Multi-Criteria Decision Analysis (MCDA) and Life-Cycle Assessment methodologies. It first reviews environmental Life-Cycle Assessment (LCA), introduces the main challenges and perspectives, including how to extend LCA towards Life Cycle Sustainability Assessment (LCSA), and discusses how LCAs might be useful for the MCDA practitioner. Then, it discusses how MCDA can complement LCA. Challenges and perspectives are presented concerning LCSA, relative versus absolute evaluation, criteria weighting, and criteria selection.

## 1 Introduction

Environmental Life-Cycle Assessment (LCA) is a well-known methodology in the fields of industrial ecology and environmental management. It aims at quantifying the environmental impacts of a product or service in a holistic and integrated manner, over its life cycle, on different dimensions called impact categories. This is fundamental to avoid shifting burdens between environmental impacts or from one part of the product life cycle to another (e.g., from production to consumption). The standardized LCA methodology (ISO 2006a, b) addresses only environmental aspects, usually giving rise to multiple impact indicators (e.g., depletion of resources, impacts of

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emissions on the environment and on human health). Over time, however, LCA-based approaches have emerged that focus on Life-Cycle Costing (LCC), Social Life Cycle Assessment (SLCA) and, more recently, in a multi-dimensional approach to sustainability, Life Cycle Sustainability Assessment (LCSA = LCA + LCC + SLCA) (Kloepffer 2008).

Multi-criteria decision analysis (MCDA) is an approach to evaluate alternatives (policies, projects, etc.) in the context of selection, ranking and classification problems. MCDA recognizes that most decisions involve the need to compromise between conflicting objectives. It explicitly acknowledges multiple evaluation criteria, which allows one to incorporate the concerns of multiple stakeholders. The performance of each alternative on each criterion is assessed, and these performances are then aggregated to derive a recommendation. Typically, aggregation involves criteria weighting.

Many authors have proposed joining LCA and MCDA for a combined assessment. Pioneering work in the period 1995–2005 includes applications (Bloemhof-Ruwaard et al. 1995; Spengler et al. 1998; Azapagic and Clift 1999; Geldermann and Rentz 2005) and some of the first frameworks (Miettinen and Hämäläinen 1997; Hertwich and Hammitt 2001; Seppala et al. 2002). In this chapter, we focus on discrete MCDA methods for brevity's sake, but we should also mention the potential of combining LCA with multi-objective optimization (Azapagic and Clift 1999) and data envelopment analysis (Thore and Freire 2002; Martín-Gamboa et al. 2017).

The number of publications reporting work that combines LCA and MCDA has been growing steadily. A recent review of work combining MCDA and LCA appears in (Zanghelini et al. 2018), who found 12 articles in 1995–2005, 18 articles in 2006–2010, and 61 articles in 2011–2015. They also reported 17 articles in 2016 alone, and replicating their methodology we have found 29 applications in 2017. This number was obtained by searching for "(multicriteria OR multi-criteria) AND (lif*cycle OR lca OR lcia)", a search that might miss articles using the expression "multiattribute", for instance, but which nonetheless indicates the growing popularity of LCA-MCDA applications. Applications can be roughly divided in two groups: one consists of MCDA applications where some of the criteria correspond to LCA categories, so that the measurement of the performance on those criteria follows a life-cycle perspective; the other consists of LCA studies that are complemented a posteriori by an MCDA aimed at synthetizing the LCA results to recommend a choice, a ranking, or a classification of the assessed alternatives. Besides these uses to support, interpret, or integrate LCIA results, MCDA can also be used to support decisions on how to conduct the LCA, for example, when selecting impact categories or defining the allocation approach (Zanghelini et al. 2018).

LCA and MCDA share the perspective that multiple dimensions of assessment are required to inform decision making. Each field offers something to complement the other. LCA can be helpful for the MCDA practitioner, since it aids in defining the set of criteria and how performance on these criteria can be measured. This is presented on Sect. 2, which reviews LCA and related methodologies. Conversely, MCDA can be helpful for the LCA practitioner, since it assists Decision Makers (DMs) in making sense of the results without inadvertently biasing them (Dias and Domingues 2014).

This is discussed on Sect. 3, which briefly reviews the main characteristics of MCDA. Section 4 discusses challenges and offers some perspectives concerning LCA-MCDA applications.

## 2 Life Cycle Assessment

Environmental Life Cycle Assessment (LCA) is enjoying increasing international recognition in the scientific community (high number of articles published in prestigious international journals, e.g., Poore and Nemecek (2018)), in industry (numerous private sector LCA studies), and in environmental policy. LCA and “Life Cycle thinking” are increasingly important for the development of key environmental policies, such as the European Union Integrated Product Policy. This targets environmental improvements and better product performance to support long-term industrial competitiveness and contribute to sustainable development (European Comission 2003). In the past, product-related environmental policies tended to focus on industrial emissions or waste management issues. However, the environmental impacts throughout product life-cycles must be addressed in an integrated way, not least to avoid shifting from one part of the life cycle to another.

The first studies addressing product life cycles are from the late 1960s. At that time, the focus was on energy and raw materials. In the early 1990s, LCA emerged in an organized form, addressing various categories of environmental impacts. The first LCA guide was published in 1992 by the Institute of Environmental Sciences of the University of Leiden (Heijungs et al. 1992). A few years later, the International Organization for Standardization (ISO) published the first LCA standards (ISO 14040: 1997—“Environmental management—Life cycle assessment—Principles and framework”, etc.). In 2006, the four original LCA standards were replaced by two: ISO 14040 and 14044 (ISO 2006a, b). According to the ISO standards, LCA addresses the environmental aspects and potential environmental impacts throughout a product life cycle from the extraction of raw materials, through production, use, end-of-life treatment, recycling and final disposal, that is, from “cradle-to-grave”. The LCA methodology is organized into four phases, as represented in Fig. 1 (left part).

The goal and scope definition includes the system boundary, functional unit, and level of detail, which depend on the intended use of the study. Figure 2 shows an example for an LCA of soybean-based biodiesel, addressing three alternative pathways: biodiesel totally produced in Brazil and exported to Portugal (A); biodiesel produced in Portugal using soybean oil (B); and soybean imported from Brazil (C). It illustrates the definition of a system boundary (the unit processes accounted for by the LCA) and the functional unit (which provides a reference for calculating the life cycle impacts, in this case, 1 MJ of biodiesel energy content). The functional unit is a key and unique element of the LCA methodology. It ensures the comparability of LCA results, which is particularly critical when different systems are being compared. The life cycle inventory analysis (LCI) involves the compilation and quantification

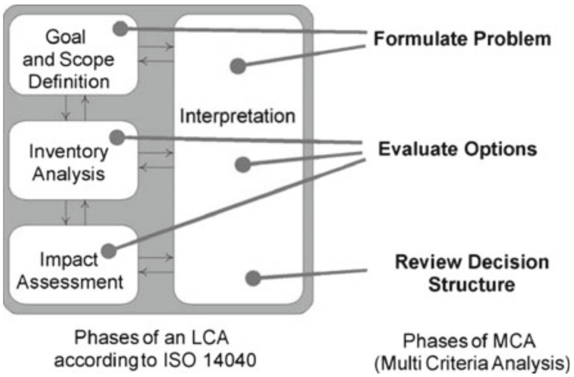


**Fig. 1** The phases of LCA and their correspondence to MCDA phases (Geldermann and Rentz 2005)

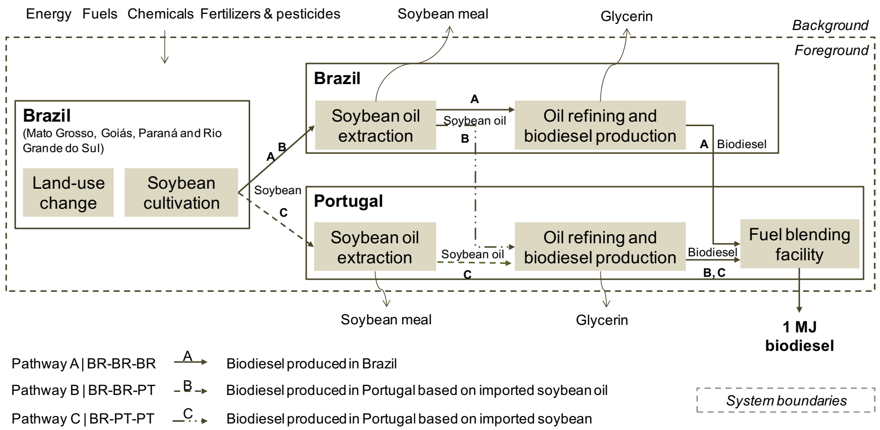


**Fig. 2** Identification of a system boundary and a functional unit: the example of a life-cycle assessment of soybean-based biodiesel in Europe (functional unit = 1 MJ), comparing different pathways (Castanheira et al. 2015)

of the input/output data of the product system. The life cycle impact assessment (LCIA) involves associating LCI data with specific environmental impact categories and category indicators. It uses factors calculated by impact assessment models on the basis of impact pathways, generally considering three areas of protection: human health, natural environment, and natural resource use.

LCIA has mandatory elements, such as selection, classification, and characterization, which lead to the calculation of category indicator results, as well as optional elements, such as normalization, grouping and weighting. Normalization—the calculation of the magnitude of the category indicator results relative to some reference information—serves to highlight the relative magnitude of each indicator. It can use external references (e.g., the total impacts for a given area: global, regional, or national) or internal references (e.g., a baseline scenario, such as a given alternative product system). Grouping is the assignment of impact categories to one or more sets (ISO 2006b). Weighting aggregates different impact category results into a single score based on weights allocated to each impact category. This is very subjective—and hence, controversial—and it implies a value judgement, which may influence the results and conclusions of an LCA. As stated in ISO (2006b), "weighting shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public". However, weighting is commonly used in studies due to its practicality for comparing impacts of different products or scenarios, supporting decision-making and communication of results (Pizzol et al. 2017). There are several LCIA methods (CML, ReCiPe, IMPACT World+, etc.), which can be organized into two main groups according to the level of the cause-effect chain: (i) midpoint methods (also known as problem-oriented methods), which provide indicators at a level of the cause-effect chain between emissions/resource consumption before the endpoint for environmental problems (climate change, ozone depletion, eutrophication, acidification, etc.); and (ii) endpoint methods (also known as damage-oriented methods), which provide indicators at the level of areas of protection against environmental damage. Endpoint methods permit straightforward communication of the LCIA results, but with considerably higher uncertainty than midpoint methods. It should be also noted that some LCIA methods, such as ReCiPe, have both midpoint and endpoint indicators and some impact categories do not have a natural midpoint (e.g., water or land use) (UNEP SETAC 2016).

Interpretation is the final phase of the LCA, in which results are summarized and discussed as a basis for conclusions, recommendations, and decision-making. LCA is iterative (as shown in Fig. 1) and as data are collected or LCIA is performed, various aspects may require modification, including the goal and scope definition.

## 3 Aggregation of LCA Results

Choosing between environmental profiles involves balancing different types of impact and is typical of multi-criteria decision problems, in which explicit or implicit trade-offs are needed to construct an overall judgment.

Generally, MCDA methods are applied to provide decision support to one or more DMs in choosing an alternative based on the consideration of multiple criteria. Since the preferences of DMs are also considered, their participation in the process is crucial (Belton and Stewart 2002). Besides comparing alternatives via a multi-criteria assessment, it is also the goal to offer DMs a structured decision process. As a result, MCDA methods increase the transparency of the decision process and make complex decision problems easier to understand (Belton and Stewart 2002; Greco et al. 2016).

The process of conducting an MCDA comprises three high-level steps with a fluid transition between them: problem formulation, evaluation of options, and review of

**Table 1** A taxonomy of MCDA methods (adapted from (Dias et al. 2015))

| | | Does the evaluation of one alternative depend on other alternatives belonging to *A*? | |
|---|---|---|---|
| | | *No (evaluation independent of other alternatives)* | *Yes (evaluation relative to other alternatives)* |
| Underlying approach | *Value* | Global value aggregating individual performances, e.g.:<br>• Weighted sum<br>• MAVT/MAUT | Global value synthetizing comparisons of alternatives in *A*, e.g.:<br>• AHP/ANP<br>• PROMETHEE II |
| | *Distance* | Distance to an externally defined reference, e.g.:<br>• Euclidean distance<br>• Chebyshev distance | Distance to a reference defined from *A*, e.g.:<br>• TOPSIS<br>• DEA |
| | *Binary relations* | Binary relation between alternative and external references, e.g.:<br>• ELECTRE TRI | Binary relation on the alternatives in *A*, e.g.:<br>• ELECTRE I–IV<br>• PROMETHEE I<br>• NAIADE |
| | *If-then rules* | Rules based on thresholds, e.g.:<br>• Dominance based rough set approach (DRSA) | Rules based on binary relations on *A*, e.g.:<br>• DRSA |

the decision structure (Belton and Stewart 2002; French and Geldermann 2005). These steps are presented in Fig. 1 (right side) alongside the phases of an LCA study.

Several aggregation methods (for an overview see, e.g., Greco et al. 2016) are available to formally evaluate the options (Table 1). Depending on the underlying decision context, some methods are more suitable than others (Roy and Słowiński 2013). Naturally, different decision methods may generate different results from the same data (Lahdelma et al. 2000). Therefore, the choice of a particular method or combination of methods (Marttunen et al. 2017) should be matched to the application (Baudry et al. 2018).

The MCDA method and the decision process are guided by an analyst (or facilitator), who gathers the information needed for problem structuring and supports the required methodological competence (Ormerod 2014). Sometimes, a decision is to be made by a group, which means that there are probably conflicting interests to be considered. In this case, MCDA provides a way to structure the dialogue between DMs (Slotte and Hämäläinen 2015).

MCDA methods thus permit DMs to consider personal preferences (e.g., in the form of weights) and witness the impacts of their choices. The discussions that take place among stakeholders with diverging positions also increase the acceptance of the ultimately chosen alternative (Renn et al. 1997; Belton and Stewart 2002; Stirling 2006; Munda 2008; Lerche et al. 2017).

## 4 Challenges and Perspectives

This section discusses several issues that confront the actors (LCA experts, MCDA experts, and other) involved in LCA-MCDA applications.

### *4.1 Towards LCSA*

The standardized LCA methodology (ISO 2006a, b) addresses only environmental aspects, usually giving rise to multiple impact indicators (e.g., depletion of resources, impacts of emissions on the environment and on human health). Over time, however, LCA-based approaches have emerged that focus on Life-Cycle Costing (LCC), Social Life Cycle Assessment (SLCA) and, more recently, on a multi-dimensional approach to sustainability (Life Cycle Sustainability Assessment; LCSA = LCA + LCC + SLCA) (Kloepffer 2008).

Guinée (2016) distinguished three dimensions along which LCSA is expanding when compared to LCA: (i) broadening impacts by including social and economic indicators, (ii) broadening level of analysis from predominantly product-related questions to sector-wide and economy-wide questions and analyses, and (iii) deepening analysis to add physical, economic, and behavioral relations to the existing technological relations, and to include more mechanisms to account for interrelations among the system elements, uncertainty analysis, and stakeholder involvement. Application of LCSA requires integration of various methods, tools, and disciplines. According to Guinée et al. (2011), structuring, selecting, and making the plethora of models practically available for different types of life cycle sustainability questions is the main challenge. The challenges associated with an increasing number of indicators from LCSA studies include how to communicate results to DMs and how to evaluate and aggregate the indicator results. Here, the application of MCDA can be very helpful.

### *4.2 Criteria Selection*

MCDA applications that involve LCA or SLCA may also consider other criteria, such as security, convenience, and aesthetics. All these applications entail making some choices about the criteria that are used. In the simplest case, MCDA is used exclusively to aggregate environmental LCIA indicators (according to CML, ReCiPe, or other LCIA methods). Special care should be taken when weighting the criteria.

Redundancies (double-counting) might arise if LCIA indicators from different methods are used. Moreover, some impacts are included as a single indicator in some LCIA methods (e.g., eutrophication in TRACI), but as multiple indicators in other methods (e.g., maritime eutrophication and freshwater eutrophication in ReCiPe). This affects results when the analysis considers all criteria on an equal basis rather than eliciting weights. Even if weights are elicited, however, the splitting bias might cause the total weight to increase when an indicator is decomposed (Jacobi and Hobbs 2007).

The selection of indicators coming from a method such as ReCiPe can be done at the midpoint or endpoint level. Eliciting weights might be simpler at the endpoint level, since there are fewer criteria at that point. On the other hand, however, these are possibly harder to trade-off then. For the same DM, eliciting weights at these two levels might even lead to different conclusions when comparing alternatives (Du 2017).

Besides environmental indicators, a more comprehensive LCSA assessment will also incorporate economic and social indicators, as mentioned in the previous section. In such cases, a choice must be made between considering a hierarchy of criteria vs. a flat structure. In the first case, there are three main criteria (environmental, cost, and social impact), each one decomposed into lower-level criteria. In the second case, the criteria are all at the same level (no hierarchy). Again, this means that the analyst must be concerned with effects caused by decomposition bias. When assessing products, productive processes, etc., there may also be other dimensions to account for that do not derive from a life-cycle perspective, such as how user-friendly or appealing a product is to its consumers.

To address these issues, MCDA has a rich literature on problem structuring that can be useful in guiding criteria selection (e.g., (Keeney 1992; Neves et al. 2009)) and on weighting biases that might derive from these choices (Jacobi and Hobbs 2007). Adequate communication between analysts and DMs is essential to ensure that the meaning of the indicators is well understood in weight elicitation processes. Lastly, when in doubt, trying out different analyses (e.g., at the midpoint and at the endpoint level) may yield additional insights.

## *4.3 Actors to Be Involved*

The majority of environmental decision problems involve uncertainty and risk. By their very nature, the estimates and long-term forecasts required in LCA are uncertain. For reviews discussing different types of uncertainty, variability, and risk, see (French 1995; Huijbregts 2001). The scale of the impacts and when they are incurred is also an important differentiator. In particular, there is little agreement on how to evaluate options with very long term impacts (Atherton and French 1999). In the context of LCA, cultural differences can be easily identified: e.g., the German scientific literature on technique assessment is fairly concentrated on risk assessment, whereas, in the UK, there is a wide recognition of the need to include socio-political issues more explicitly into the decision making (French and Geldermann 2005).

There are many parties to such decisions. DMs are responsible for making the decision; they 'own the problem'. They are accountable to some, but not necessarily to all the stakeholders in the problem. Stakeholders share, or perceive that they share, the impacts arising from a decision. They have a claim, therefore, that their perceptions and values should be taken into account. Experts provide economic, engineering, scientific, environmental, and other professional advice used to model and assess the likelihood of the impacts. The DMs may have technical advisors who are undoubtedly experts in this sense, but they are unlikely to be the only experts involved. Other experts may advise some of the stakeholders, thus influencing the stakeholders' perceptions and hence shaping their decision making. Analysts develop and conduct the analyses, both quantitative and qualitative, which draw together empirical evidence and expert advice to assess the likelihood of the outcomes. They will also be concerned with a synthesis of the DMs' and stakeholders' value judgements. These analyses are used to inform the DMs and guide them towards a balanced decision. Whereas experts support decision making by providing information on the content of the decision, analysts provide process skills, thus helping to structure the analysis and interpret the conclusions. This separation of roles is much idealized; some of those involved may take on several roles. Clearly, DMs are necessarily stakeholders because of their accountabilities; but they may also be content experts and may conduct their own analyses. Similarly, experts may be stakeholders and vice versa.

### *4.4 Criteria Weighting*

MCDA typically elicits preferences from a DM or a group of DMs, acknowledging the legitimacy of considering their subjective preferences. An MCDA analyst's job is to support the decision process of the DMs so that they obtain recommendations as compatible as possible with their value system. A company performing MCDA on LCA indicators can also proceed in this manner according to its policies and preferences. To select suppliers or evaluate potential changes to its product range or productive processes, for instance, a company may conclude that option $x$ is better than option $y$. Similarly, a government department can proceed in this manner following its policies and priorities, for instance, to sort products into categories for taxing purposes. Here, concluding that $x$ is better than $y$ thus reflects the policies and priorities of the company or the government, and not an objective truth.

In LCA, however, there is often no DM involved in the analysis, and the implicit perspective is that the alternatives are being objectively evaluated according to the best scientific state of the art. This is probably why the LCA standard ISO 14044:2006 states that weighting LCIA indicators is an optional step in the methodology and should not be used for comparative assertions intended to be disclosed to the public.

There are attempts to circumvent subjectivity by deriving weighting vectors backed by science. LCIA endpoint indicators, for instance, already aggregate multiple LCIA midpoint impact indicators considering more generic dimensions (the so-called areas of protection), such as "Damage to human health", with weights that attempt to capture the relative damage pathways caused by each different impact (climate change, particulate matter, ionizing radiation, etc.). Soares et al. (2006) suggested obtaining weights by using a panel to score the importance of LCIA indicators on attributes such as scale, duration, reversibility, etc. Another proposal to derive weights backed by science is to associate the weight of an indicator with the seriousness of the impacts with regards to planetary boundaries (Tuomisto et al. 2012): if the impacts in a given category have gone beyond the limits that our planet can stand as a "safe operating space" for humanity, then it should have a high weight; if the impacts are far away from this boundary, the category could be assigned a lower weight. Nevertheless, all these proposals are still subject to large uncertainties due to lack of consensus in the scientific community about how midpoint indicators translate into higher order consequences.

Given the concern about the subjectivity of weighting, many LCA studies simply assume all indicators have the same weight, sometimes considering other "scenarios" (i.e., weight vectors) that place more weight in different groups of criteria. From an MCDA perspective, however, the concept of equal weights is meaningless in some methods (e.g., when a normalization or a value function is used) and setting all weights to the same value is still a subjective choice. Ultimately, one might simply accept that obtaining a purely objective result is an impossible goal, since there is subjectivity in the choice of alternatives that are evaluated, the choice of what criteria are considered, and even the choice of an MCDA method. One might even argue that LCA itself already brings subjective choices when defining system boundaries, allocation method, etc. (Myllyviita et al. 2014).

If the subjectivity of weighting is acknowledged, then the main concern should be that weights are adequately elicited from the DMs (or panels of experts or citizens on their behalf) and made transparent. First, it should be acknowledged that different MCDA methods are associated with different meanings for the criteria weights. Therefore, weights cannot be elicited without defining beforehand what MCDA method is being used, including the possible definition of normalization processes (Myllyviita et al. 2014), and following elicitation protocols adequate for the chosen method (e.g., (Dias and Mousseau 2018; Morton 2018)). The choice of the MCDA approach should reflect considerations of the study's purposes and needs, in particular, the issue of compensatory versus non-compensatory aggregation (Guitouni and Martel 1998).

Regardless of the process used to define weights, the concerns about choosing a vector of weights can be mitigated if one adopts an incomplete/partial information perspective. This means acknowledging multiple and equally acceptable criteria weight vectors $w \in W$ (W being a set of weights large enough to accommodate the analyst's concerns). A "robustness analysis" can then be used to determine the worst possible result for each alternative (a cautionary perspective), along with the best possible result (a benefit-of-doubt perspective), as proposed by (Domingues et al. 2015). Stochastic analysis is another way to study a problem according to an SMAA-type approach, simulating results for randomly sampled weights, as suggested by (Prado-Lopez et al. 2014). Robustness and stochastic analysis can be used together to inform decision making with complementary results (Dias et al. 2016).

### 4.5 Relative Versus Absolute Evaluation

MCDA usually compares several alternatives, which is not the case in many LCA studies. Indeed, some LCAs are devoted to assessing the impacts of a single product or service, for instance, with the aim of learning which stages of the life cycle have the greatest impacts. Often an LCA study is performed to compare a new or modified product with an existing one. Clearly, MCDA methods that base their recommendations on a competition among alternatives, assessing how each one compares to each other one (e.g., AHP, PROMETHEE and most ELECTRE methods), cannot be used if there is a single alternative to be evaluated.

A possible solution to this issue is to use MCDA methods that evaluate one alternative at a time, independently of any other alternatives (Table 1). Such methods assign a global value or category, respectively, to each alternative according to predefined parameters (value functions, category profiles) without comparing it to other alternatives being considered. Nevertheless, they still require setting parameters or fictitious alternatives that often depend on the anticipated range of performance scores.

Another solution might be to add more alternatives, possibly fictitious or irrelevant, to allow a richer comparative analysis. However, this raises another concern in the relative vs. absolute evaluation debate, which is the independence with regard to irrelevant alternatives. Indeed, methods based on pairwise comparisons (AHP, PROMETHEE, most ELECTRE methods, etc.) do not provide this independence. If their recommendation is that A is preferred to B, and B is preferred to C, then removing C or adding a new alternative D might lead to the conclusion that B is preferred to A (the rank-reversal problem) (Millet and Saaty 2000; Wang and Luo 2009).

It should be noted that even methods not based on pairwise comparisons can be affected by rank-reversal issues (Wang and Luo 2009). One possible reason is that alternatives are compared with an ideal and/or anti-ideal solution (as occurs in TOPSIS and similar methods), which can change when adding or removing an alternative. Another reason is that many methods (e.g., the weighted-sum method) require normalization approaches, and some of these approaches are based on the performances of the best (and sometimes also the worst) alternative regarding each criterion. Again, this can cause reversals when adding or removing an alternative (Dias and Domingues 2014). To address this issue, a "status quo" normalization (Domingues et al. 2015) can be used instead. Avoiding the need for normalization is an advantage of some relative evaluation methods (Prado-Lopez et al. 2014),

## 5 Conclusions

LCA and MCDA communities can benefit from each other by mutual learning and exchange of ideas. To begin with, LCA is already multi-criteria by its very nature. The impact categories are assessed separately in incommensurable units of measurement and are usually in conflict with each other. Therefore, LCA and MCDA share the perspective that the consideration of multiple criteria is in general the most adequate way of supporting decision making.

Increasingly, DMs in engineering and business settings are required to select the “most sustainable” alternative, or to at least consider environmental and social responsibility concerns. MCDA practitioners involved in such decision problems might easily forget important issues. They might omit life cycle stages, impact categories, or impacts in other geographies, for example, or they might lack consistency in their assessments. In such settings, the LCA or LCSA framework can be extremely helpful for the MCDA when structuring the set of criteria. In particular, LCSA directs the MCDA practitioner to consider environmental, social, and economic criteria, thus broadening and deepening the level of analysis. It therefore contributes to a more comprehensive evaluation and helps ensure that all the concerns of DMs and stakeholders are included in the analyses. Moreover, LCSA aims at measuring the performance of the alternatives on many environmental and social criteria where a life cycle perspective is in order. The existence of standards and software facilitating the computation of results is another advantage the analysts can appreciate. DMs and analysts can thus understand that finding the “most sustainable solution” is an elusive goal, observing how alternatives compare to each other on multiple impact categories, and possibly also how they compare with external references.

On the other hand, MCDA theory and methods are needed to make adequate use of LCA or LCSA results for decision aiding purposes. This applies not only to the aggregation of impact categories, but also to all other problems (probably most of them) where additional criteria not encompassed by LCA are important (e.g., reliability, ease of maintenance, throughput time, comfort, etc.). MCDA is a field of knowledge that offers methods to define and structure a set of evaluation criteria, to guide the dialogue between analysts and DMs, to set parameters that reflect preferences (namely criteria weights), and to aggregate all the information in a logical manner. Moreover, MCDA makes decisions transparent and auditable, which is especially important if there is no absolute truth.

As a consequence, we expect that the already large number of MCDA-LCA/LCSA applications will continue to grow, and that LCA practitioners will become increasingly knowledgeable about MCDA methods, and vice versa. LCA practitioners will tend to use a reduced number of MCDA approaches that will become increasingly popular in this area. We thus expect that proper application of LCA and MCDA will become state of the art both in science and in practice. Yet, many more studies are needed regarding the acceptability of different approaches and their adequacy to inform decision making in real-world situations.

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