Valuation: A Societal Approach

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ABSTRACT

This paper presupposes that valuation in LCA has a purely normative meaning. The interpretation of a stated preference is addressed, and a formalism which uses the concept of elasticity is developed. It is shown how elasticity relates to weighing factors, and what the relation between valuation and normalisation is. The importance of studying social decision theory is stressed. Another message is the fact that it requires a careful analysis to find a sensible interpretation for social opinion, and that a reproducible result does not guarantee any truth.

1. INTRODUCTION

According to most reports in the field of LCA, the valuation step is not very well elaborated. Valuation is about the weighing and aggregation† of different environmental impact categories in order to compress multi-dimensional information into a judgement. The literature cited agree on the fact that valuation is mainly based on social preferences and values. Nevertheless, there are many examples in literature (see Anonymous, 1993, or the paper by Tukker *et al.* elsewhere in this proceedings) of a valuation on a natural science basis in which there is no or only a very limited social element included.

In this paper, it will be assumed that valuation is purely normative. This means that sustainability levels are not used to weigh environmental problems. Knowledge of sustainability levels may of course influence the opinions on the severeness of certain environmental problems, but the point is that there is no formula in which sustainability factors determine the weighing factors.

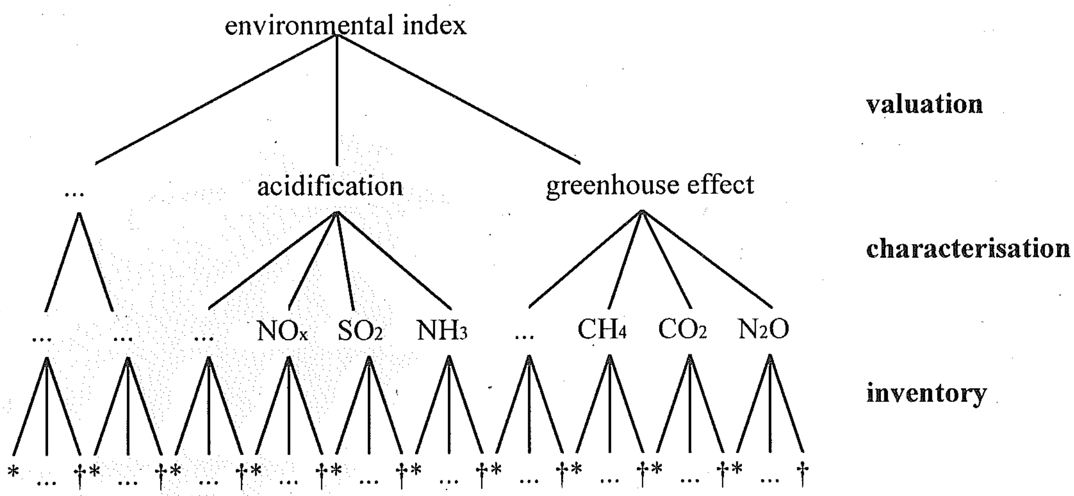
In social decision theory, several methods to support decision making on the basis of multi-dimensional information have been developed. Methods to be found in literature include multi-attribute utility theory (MAUT), analytic hierarchy process (AHP), impact analysis matrix (IAM), and multi-criteria analysis (MCA). For some background information in environmental applications, see e.g. Driessen *et al.* (1991), Fava *et al.* (1993), and Maystre *et al.* (1994). Multi-attribute utility theory is about using different attributes (different environmental effects‡) to arrive at a decision, so about combining these attributes into one index. See Figure , Huppes & Guinée (1992), and Baumann & Rydberg (1992). It differs in this respect from the other tools, which are either more a procedure than a quantitative technique, or are more a way of presentation in a suitable form. The theory developed in the context of MAUT poses some requirements to LCA. The quantities in the inventory analysis as well as in the characterisation have to be defined on a ratio scale.

The different attributes on one level, e.g. the environmental problems acidification, greenhouse effect, etc., have to be independent and complete, i.e. they should not overlap nor should they have lacunae. For the valuation a decision rule, a combination rule, and weighing factors are needed. These last two aspects will be elaborated in the next sections.

† It is important to observe that valuation is not only aggregation, but is also interpretation. It is sometimes said that valuation is useless, as useful information is lost. This is not true if intermediate results are saved: it can be very instructive to know that the total environmental index of a product is 23, and that emission of SO_2 during transportation is responsible for 14.

‡ The word utility is derived from the desire to maximize a score. A more appropriate word in the assessment of environmental criteria is therefore multi-attribute dis-utility theory (MAdUT).

Figure 1 ***A decision tree suitable for lca. The first aggregation takes place in the inventory analysis, the second one in the characterisation, and the last one in the valuation.***



2. A FORMALISM

Formalised, the situation can be described as a set of alternatives (products) $\{A_1, A_2, \ldots, A_a, \ldots\}$ of which all elements are known to have values for a number of criteria (environmental effects) $\{C_1, C_2, \ldots, C_c, \ldots\}$. The scores or values can be represented as a function S which maps A_a and C_c onto S_{ca}: $S_{ca} = S(C_c, A_a)$.

The problem is to aggregate the different scores per product to one number: the environmental index I_a. A very general form to do this is with a weighted aggregation. Mathematically expressed:

$$I_a = \sum_c W_c ¢ f(S_{ca}) \qquad (1)$$

where W_c is the weight of the cth criterion, and $f(S_{ca})$ is a function of the effect score that belongs to the cth criterion for the ath alternative; f could for instance be a square or a logarithm. Observe that W_c does not depend on the alternative a: the weighing factors are independent of the product under consideration. The equation shows that two aspects are of interest*:

- the combination rule;
- the weighing factors.

Both topics need to be addressed.

3. THE COMBINATION RULE

The question of the combination rule is often neglected: the function f is simply assumed to be linear. This is, however, not obvious. In a related context, environmental impact assessment, a non-linear form is often used, either implicitly or explicitly. The reason for doing so is the fact that EIA is about actual effects, and that an alternative that meets the legal standards for all criteria is automatically superior to an alternative which exceeds a standard for one impact category, even if it is much better on all other impact categories. This can never be achieved by a linear combination rule.

* Another topic is the decision rule: do we wish to rank the alternatives, do we wish to select the best, the worst, or the best three? An answer to this question could make that a simpler equation suffices. This paper will assume, however, that the most general form is required.

As LCA is concerned with potential effects (Heijungs & Guinée, 1994), and as it does not make sense to speak in LCA about exceeding a standard, a linear combination rule could be defended.
Another reason is the arbitrariness of the functional unit: it seems natural to require that the ratio between the environmental index of two alternatives is invariant for a change in the unit of function considered†. A third reason could be the assumed marginality of the functional unit, in conjunction with the *ceteris paribus* postulate (Heijungs *et al*, 1992)‡. All three arguments point in the direction of a linear weighted aggregation, e.g. one of the form

$$I_a = \sum_c W_c \not{c} S_{ca} \qquad (2)$$

It must be emphasised, however, that these arguments still do not provide a rigid proof for a linear combination rule.

4. THE WEIGHING FACTORS

After having chosen the aggregation form of (), weighing factors have to be supplied. As stated in the introduction, this paper will take the point of view that the weighing factors be socially determined. Thus, forms like that of Sas *et al.* (1994): $W_c = \frac{N_c - S_c}{S_c}, \frac{1}{N_c}$, where N_c is the current extent of a certain problem and S_c the sustainable level, will not be considered. It is assumed that the factors W_c are directly derived from questionnaires or interviews. Instead of reconstructing preferences from decisions in the past (revealed preference), a stated preference will be used. A problem is, however, that it is not clear how to obtain weighing factors from a stated preference. This problem is, like the presumed linearity of the combination rule, often ignored. It can be illustrated by an example.

4.1. Choosing a sleeping bag

Suppose you want to buy a sleeping bag, and that the criteria which are relevant for making a choice are price and mass. The profile for every sleeping bag therefore consists of two criteria: a score S_p for the price and a score S_m for the mass. The profile for two sleeping bags are:

criterion	sleeping bag 1	sleeping bag 2
S_p (price) in $	100	200
S_m (mass) in kg	3.00	2.00

One approach would be that the shopkeeper asks what you, personally, considers to be more important, price or mass. Suppose that you answer by stating that mass is more important by a factor 3. Assuming a linear combination rule as $I = S_p + W \times S_m$. This would lead to $I_1 = 109$ and $I_2 = 206$, so that sleeping bag 1 would be preferred to sleeping bag 2.
What immediately strikes, however, is that there must be an error somewhere in this approach. Both price and mass are expressed in arbitrarily chosen units, whereas the preference was stated regardless of units. For example, when the mass would have been expressed in g instead of kg, one would have $I_1 = 9100$ and $I_2 = 6200$, so that sleeping bag 2 would be preferable.
There are two solutions to overcome this problem:

- ask an alternative question;
- give an alternative interpretation to the answer.

The first solution would for instance amount to the inclusion of the unit in the question.

† This amounts to requiring that, if 100 l milk in glass bottles is twice as bad as 100 l milk in polycarbonate bottles, 500 l milk in glass bottles should also be twice as bad as 500 l milk in PC bottles.

‡ The marginality of the functional unit means that the environmental effects of the functional unit are small compared with the total environmental effects. Under the *ceteris paribus* postulate it is assumed that the environmental effects of the rest of the economic system does not depend on the product alternative chosen.

An example of such a modified question could be: "How many $ are you prepared to pay for 1 kg less mass?" The answer would then be a weighing factor which is not any longer a dimensionless 3, but which is, for instance, 100 $\$ \cdot kg^{-1}$.

In the second solution it is assumed that the stated preference factor of 3 somehow makes sense. The problem is therefore to find its meaning*. A candidate for this could be an interpretation in terms of an elasticity. The shopkeeper could interpret the answer as: "Apparently, you are prepared to pay 3% more for 1% less mass."

Which is the best solution? The first solution – asking a question including units – has a disadvantage. It is conceivable that stating a preference including units works for some appealing cases. But it will certainly not work for less tangible instances, as occurs e.g. in the field of environmental decision making. Nobody can answer a question like: "How many kg SO_2-equivalent of acidification do you tolerate for 1 kg CO_2-equivalent less greenhouse effect?" The second solution – using the concept of elasticity – does not have this disadvantage, but requires a well-defined reference situation, e.g. a particular sleeping bag. Again, this reference situation must be tangible in order to get sensible answers.

4.2. From elasticity to weighing factor

It thus seems that an interpretation in terms of elasticity needs to be elaborated. The elaboration consists of three elements:
- a tangible reference situation has to be chosen;
- a sensible question has to be asked;
- a conversion from the answer to a weighing factor has to be made.

It may be argued that the most tangible reference situation is the current level of environmental problems. This would lead to a question like: "How many % more acidification do you tolerate for 1% less greenhouse effect?"
Suppose that the answer is: "3%." This number has to be converted into a weighing factor which can be applied in the combination rule. Also suppose that the combination rule in this simple case is

$$I(S_A, S_G) = S_A + W_G \times S_G \tag{3}$$

where S_A is the effect score for acidification, S_G is the effect score for greenhouse effect, and W_G is the weighing factor for greenhouse effect (relative to acidification). The stated preference says that the current scenario has the same preference as a scenario with 1% less greenhouse effect and 3% more acidification. This means that the environmental index of these two scenarios is equal. Indicating the current level of greenhouse effect by $S_{G,current}$ and the current level of acidification by $S_{A,current}$, the equality of the index of the scenarios amounts to:

$$I(S_{A,\,current}, S_{G,\,current}) = I(1.03 \times S_{A,\,current}, 0.99 \times S_{G,\,current}) \tag{4}$$

Using the combination rule gives:

$$S_{A,\,current} + W_G \times S_{G,\,current} = 1.03 \times S_{A,\,current} + 0.99 \times W_G \times S_{G,\,current} \tag{5}$$

so that:

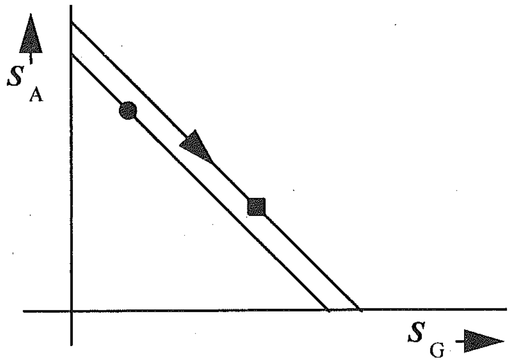
$$W_G = 3 \times \frac{S_{A,\,current}}{S_{G,\,current}} \tag{6}$$

* This resembles the situation in *The hitch hiker's guide to the galaxy*, in which after 75,000 generations Deep Thought answers the great question of Life, the Universe and Everything: forty-two, without anyone knowing what this figure means (Adams, 1979).

The weighing factor is thus related to the elasticity with a factor which depends on the reference scenario*.

Stating the elasticity of preference amounts to defining iso-preferable scenarios. Figure illustrates that scenarios define a point in a diagram, and that scenarios with the same preference can be connected with an iso-utility curve. The curve is in fact a straight line, simply because a linear combination rule was used; see equation 2. The slope of the line is related to the elasticity factor. Scenarios which are on a line that is closer to the origin have a higher preference.

Figure 2 ***The current scenario (■) and an iso-preferable scenario (▲) define an iso-utility curve. A scenario which lies closer to the origin (●) has a higher preference.***



4.3. The relation with normalisation

The weighing factor derived from stating the elasticity of the preference of a marginal change in the current scenario can be substituted in the combination rule. This gives a valuation formula for use in case studies†:

$$I = S_A + 3\,x\,\frac{S_{A,\,current}}{S_{G,\,current}}\,x\,S_G \qquad (7)$$

The form becomes more clear by redefining the environmental index as

$$I = \frac{S_A}{S_{A,\,current}} + 3\,x\,\frac{S_G}{S_{G,\,current}} \qquad (8)$$

It appears that the elasticity factor 3 can be used as a weighing factor, provided the effect scores are normalised by the current extent of the environmental problems*.

* For example, supposing that the current situation corresponds to a level of acidification of 10^8 kg SO_2-equivalent·yr^{-1} and a level of greenhouse effect of 10^{12} kg CO_2-equivalent·yr^{-1}, the weighing factor is $W_G = 3 \cdot 10^{-4}$ kg SO_2-equivalent·kg^{-1} CO_2-equivalent.

† Observe that S_A denotes in the procedure of §4.2 kg SO_2-equivalent·yr^{-1}, whereas it will in most case studies denote an effect score in kg SO_2-equivalent. The question whether this change of meaning is allowed is deliberately neglected here.

* In Kortman *et al.* (1994), an equation like 8 is used, but the question asked to obtain weighing factors had no relation with the figures used for normalization, and was not about elasticity.

This throws new light on the issue of normalisation: the scale level used in this normalisation should somehow match with the scenarios used for stating the preference of the elasticity. If the effect scores are normalised by the global extent of the problems, the question should be about global scenarios: "How many % more of the global level of acidification do you tolerate for 1% less of the global level of greenhouse effect?" If it on the other hand proves easier to answer a question like: "How many % more of the European level of acidification do you tolerate for 1% less of the global level of greenhouse effect?", the effect scores have to be normalised accordingly, and thus in an incomparable way.

Normalisation of effect scores can serve two purposes:
- it is a further interpretation;
- it is a step towards valuation.

It can be concluded that the above considerations lead to a normalisation that conforms to that type of questions about elasticity that are most tangible. If normalisation is used for only interpretational and presentational purposes, the considerations about tangibility may be neglected.

5. DISCUSSION

This paper focused on a framework for a societal approach to valuation. The approach described is only one approach. Other possibilities within MAUT include a monetary valuation or using sustainable levels as weighing factors, or a combination of the three types[†]. Other types of valuation employ AHP, IAM, MCA, or still other techniques. MAUT has been elaborated here, as it is a type of analysis which allows for the introduction of weighing factors, and does not necessarily require an expert judgement. This opens the possibility of compiling valuation factors, so that future reports on LCA methodology may contain an appendix with valuation factors, just as they contain appendices with equivalency factors.

A reliable valuation requires a reproducible set of weighing factors. Opinions may change in due course, but when the weighing factors change from day to day dramatically, something is wrong. Reproducibility is thus a necessary condition for a sound valuation. It is not a sufficient condition, however. The example of the sleeping bag illustrates this. Even if the stated preference is extremely reproducible, the way it was used as a weighing factor was wrong. This is a very important observation.

The researchers in the field of LCA have to be cautious on the truth of their methods. Sometimes one can falsify a certain proposal by detecting an inconsistency, or by *reduction ad absurdum*. When it is not possible to disqualify a certain method, it may, unfortunately, still be wrong.

The issue as to whom is or are asked to state preferences has been ignored. It seems natural that a societal approach implies asking society's opinion. This means that the weighing factors are not compiled by (environmental) scientists. Public debate, the parliament, the government, or even international bodies, such as the UN, appear to be better options. A related question is how often weighing factors are to be determined. Only when new facts have become available? Or every two years?

There remain of course many other problems. Should one state a comparative preference each time for two categories? Or should one distribute, say, 100 points over all criteria? Or should one assign a number between 0 and 10 for every criterion?

† In a forthcoming report (Anonymous, 1994), an attempt to combine sustainability levels and societally determined weighing factors into valuation factors is described. This report is conceived with a point of view that violates SETAC's opinion that valuation should be normative, and not natural-science based. In the epilogue to this author's contribution to that report, it is demonstrated that the self-imposed restriction of that report leads to a conclusion that can be brought in agreement with the conclusion from the self-imposed restriction of the present paper. In fact, conforming alternatively to the former and to the latter restriction proves to be profitable.

If it is done pairwise, can a redundant set of answers be used to check consistency, or to provide margins of uncertainty? And if two or more people are asked, should they come together and discuss and come up with a joint result, or shouldn't they have contact, in order to have once more redundant answers?

Many of these questions have surely been answered within social decision theory. Raising them here should stimulate LCA researchers to explore the knowledge acquired in that field.

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