
Indexes for Fixed and Flexible Environmental Target Setting – A Decision Analytical Perspective

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Abstract: We describe a decision analytic, structured approach for developing environmental indexes ensuring them to be explicit and problem specific. The indexes are used for setting and communicating targets related to products' environmental performance. Two index models are the fixed model based on the prevailing tradition, where announced targets must be met in every impact category, and the flexible model, where impacts are aggregated and target is announced in terms of the aggregated impact thus enabling trade-offs between the impacts. The flexible model is a new and a promising approach offering more freedom to reach the target even though more preference information must be modelled. We stress the different viewpoints of those using the index for target setting and of those whose products are evaluated with the index. We do this by differentiating between impacts and stressors and expressing the targets in terms of both. We illustrate the approaches with a hypothetical environmental labelling example.

Keywords: Environmental targets, environmental index, multiple criteria decision analysis (MCDA), trade-off, environmental labelling, life cycle assessment (LCA)

1 Introduction

The need to take environment into account in decisions has increased. In this paper, we discuss and suggest improvements in the development of indexes that can be used in environmental target setting. We describe, how different index models lead to different requirements. We focus on the environmental performance of products and services. For developing indexes to measure the environmental performance of firms, see e.g. Azzone and Manzini (1994), James (1994) and Tyteca (1996).

One area of application for indexes is environmental labelling. Environmental label is a certificate indicating that the product meets an acceptable level of environmental performance set for the product group. It has two objectives: 1. to provide the consumers information on the environmental performance of the product and, thus, to direct their choices towards less harmful products; and 2. to give industry an incentive to develop and implement less harmful materials, processes and practices. Examples of eco-labelling programmes are the Blue Angel in Germany, the Eco-flower in the European

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Union, the Environmental Choice in Canada and the Swan in Finland, Iceland, Norway and Sweden.

We describe two models for environmental index – one where all the targets have to be met separately (fixed) and one where trade-offs between different impacts are allowed (flexible). So far, in environmental target setting several issues have been usually considered separately and requirements have been set for each of them. This is in accordance with the fixed model approach. We see, however, the new flexible model as a promising approach because it offers more freedom in reaching the target even though more information on the decision makers' preferences and values has to be collected and modelled. This increased flexibility could lead to more cost-effective improvement actions taken by those whose products are evaluated with the index. The two models will be compared mathematically in the Appendix.

In both models, we distinguish between two points of view: 1. the index developers (authorities) who use the index to set, describe and communicate their environmental targets and 2. those, whose products or activities are evaluated with the index. We do this by differentiating between environmental impacts and stressors and expressing the targets in terms of both. This distinction is in accordance with the OECD (1996) work on sustainable development indicators as well as with the methodology development for environmental life cycle assessment (LCA). The same idea can also be found in quality function deployment (QFD), a design tool where a distinction is made between criteria describing the customer satisfaction (corresponding to impacts) and engineering characteristics of a product (corresponding to stressors) affecting the customer satisfaction (Hauser and Clausing, 1996).

Environmental decision making and target setting is challenging for several reasons:

- Interest groups have differing views on environmental values.
- Total environmental performance consists of several different types of impacts.
- The quantification of impacts may be complicated because of the lack of data or appropriate measurement scale.
- The interpretation of the seriousness of a certain amount of impact may be complicated because of the lack of appropriate reference level.
- The seriousness of an impact depends on the geographical circumstances.

The proposed systematic approach makes it possible to take into account the above described problems. Interest groups' values and several impacts will be addressed by using tools and approaches from multiple criteria decision analysis. In this way, incommensurable environmental issues can explicitly be considered, see e.g. Keeney (1988), Huang et al. (1995), Hämäläinen (1988, 1991, 1992), Marttunen and Hämäläinen (1996) as well as Miettinen and Hämäläinen (1997). We will utilise the decision analytical approach based on value functions and weights for environmental impacts to model the decision makers' preferences.

The field of multiple criteria decision making has two main elements. Multiple criteria decision analysis is an approach used for evaluating existing discrete alternatives.

Multiple criteria optimisation methods help to produce or select one alternative from a continuous set of alternatives. One could see that finding an optimal product in a multiple criteria sense offers interesting possibilities. In this paper, we shall not pursue this approach even if our flexible model indeed has elements of such thinking. For a survey of methods for multiple criteria decision making, see e.g. Stewart (1992).

Ever since the so-called Brundtland's commission coined the term "sustainable development" in its report *Our Common Future* (WCED, 1987), the concept has been a widely accepted goal. To operationalise it, initiatives for developing indicators for sustainable development have been taken e.g. in OECD (1996). The sustainability indicators could be used as a starting point when considering which environmental impacts to include in the index. In deciding the final set of impacts to be used, local circumstances and preferences obviously cannot be ignored.

The whole product life cycle should be quantitatively considered to ensure that all relevant impacts will be taken into account. We see life cycle assessment (LCA) as a promising method for providing objective information on the environmental performance of products in such a format that it can be utilised in the index development. In LCA, issues related to the distribution of impacts over time and over different geographical regions are addressed. Especially those parts of LCA where standardisation has progressed can provide a common approach for data collection. To date the standards on principles and framework (ISO 14040, 1997) as well as on goal and scope definition and inventory analysis (ISO 14041, 1997) have been completed. For a description of LCA, besides the ISO standards see e.g. Consoli et al. (1993); Guinée et al. (1993:1-2), Lindfors et al. (1995:2) and Owens (1996). For a discussion on objective and subjective components of LCA, see Miettinen and Hämäläinen (1997).

2 Structured approach for developing environmental indexes

We propose a structured approach described in Figure 1 for developing environmental indexes. The numbers refer to the chapters where each step is discussed in detail. In the process, results from some steps can cause the need to revise the earlier decisions.

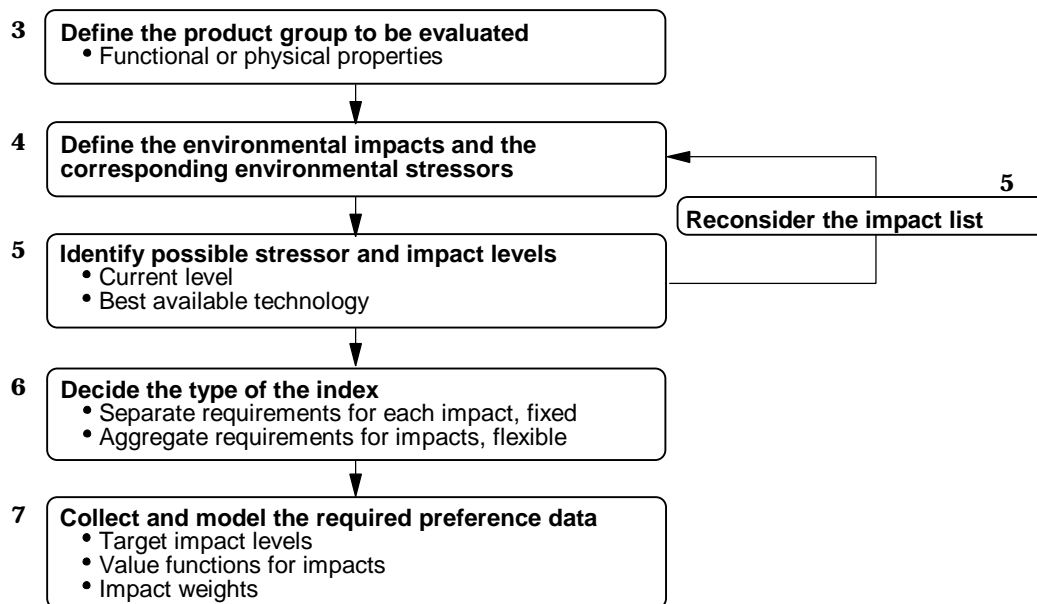


Figure 1. A structured approach for developing environmental indexes.

3 Define the product group to be evaluated

In the following, “product” refers to any physical product or service for which environmental targets are to be set. Different products can have very different impacts, which makes their comparison difficult. For example, toxic releases due to careless disposal could be the major source of impact for one product. For another product, the large consumption of non-renewable raw-materials and energy in manufacturing could cause most of the detrimental impacts. To restrict the comparison to similar products, the product group has to be defined. This definition can be based either on the products’ *physical* or *functional* properties.

In the physical approach, physically similar products belong to the same product group, e.g. all copying papers would belong to the group “copying papers” and all detergents would belong to the group “detergents”. This leads to a large number of groups, which can raise the costs of developing several indexes, because the relevant impacts and the decision makers’ preferences are likely to differ from one group to another. The advantage is that products in a certain group are not likely to differ much from each other which makes it easier to identify the impacts relevant for the particular product group.

In the functional approach, products having the same functional properties belong to the same group, e.g. newspapers and CD-discs both can be used for “storing and distributing of information”, as well as detergents and laundry services both for “cleaning clothes”. Instead of physical properties, the functional approach stresses the product’s ability to provide a certain service. This is in accordance with the LCA methodology (see ISO 14040, 1997 and ISO 14041, 1997 and Consoli et al., 1993). For example, when comparing the environmental impacts of different ways to clean clothes, instead of, say, 10 kg of detergent, the basis for comparison would be the mass of detergent

or the amount of laundry services required for cleaning of, say, 1 000 kg of laundry to fulfil certain cleanliness standards.

There are three complications related to the functional approach. The first is that products having very different impact profiles can belong to the same group. Therefore, it can be difficult to define a reasonably small, yet comprehensive set of impacts that would cover all the aspects of evaluating the environmental performance of products in the same product group. The second complication is that it can be difficult to define the exact amount of product needed to provide the required function. For example, several assumptions are needed to estimate the mass of liquid soap needed for, say, 1000 hand washes. The third problem is that besides the main service, e.g. the capacity to store and distribute information, the products can have other services very different from each other. For example a newspaper, but not a CD-disc, after having been read, can be used to fire a fireplace or to wrap a fish in it at the market place. How these other services will be taken into account should be solved as a part of the index development. For a discussion on this, see ISO 14041 (1997).

4 Define the environmental impacts and the corresponding stressors

Following the OECD (1996) approach, we define the *environmental stressors* as being the raw-material and energy requirements as well as emissions to air, water and soil in different steps of the product's life cycle, and *environmental impacts* as being the changes in the quality of the environment and the quality and quantity of natural resources resulting from the stressors.

The list of environmental impacts should be based on generally agreed principles. Sustainability as a concept has been widely accepted and could therefore be used as a starting point for defining the environmental impacts. Local conditions and political considerations can play a role in modifying the impact list. The impacts not considered important could be removed, but only after careful product group specific considerations. Other impacts of special importance could be included.

Work has been done to develop indicators for sustainable development as well as criteria for indicator selection (OECD, 1996). These criteria relate to the indicator's policy relevance and utility for users, analytical soundness as well as measurability.

Also in LCA methodology development, list of impacts representing three broad categories, namely resource depletion, human health impacts and ecological impacts, has been developed (cf. Lindfors et al., 1995:1). Owens (1996) discussed the technical feasibility and accuracy of the LCA impact categories and concluded that there are large differences between them. The LCA and OECD impact categories are summarised in Figure 2. The hierarchy lists the LCA impact categories. The bold typeface indicates that the impact category is also included in the OECD (1996) framework.

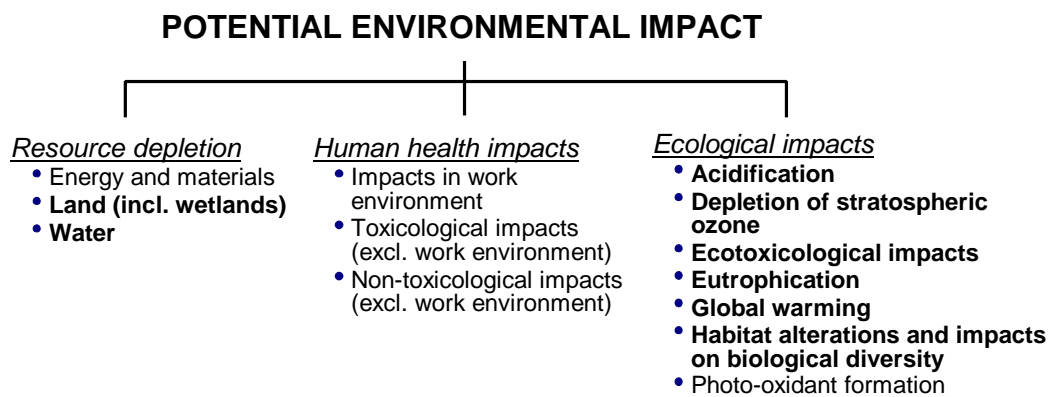


Figure 2. The environmental impact categories in the LCA and OECD frameworks (cf. Lindfors et al, 1995:1 and OECD, 1996). The bold typeface indicates that the impact is also included in the OECD framework.

We distinguish between two points of view: 1. the index developers (authorities) who use the index for environmental target setting and 2. the organisations (companies) whose products are evaluated with the index. The authorities are likely willing to think in terms of impacts, since the impacts are more closely related to environmental protection and policy goals. On the other hand, companies would like to know the requirements in terms of stressors, since the stressors are more closely related to their day-to-day actions and operations.

An approach used in LCA to describe the relationship between the stressors and impacts is first to identify for each impact those stressors that contribute to it, and then to quantify this contribution by defining an equivalency factor that indicates the relative strength of the stressor compared to some reference stressor (see e.g. Consoli et al., 1993; Guinée et al., 1993:2). The approach, which in LCA terminology is called classification and characterisation, is illustrated in Figure 3.

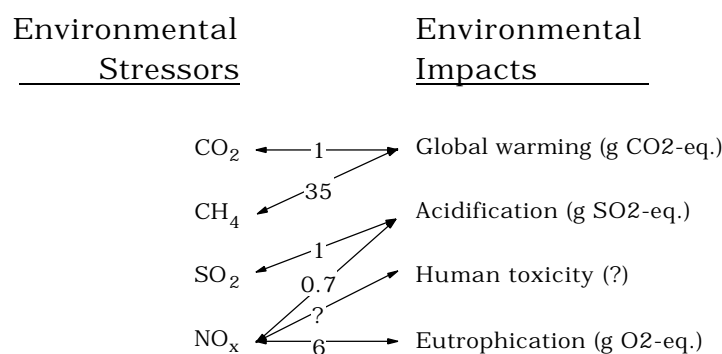


Figure 3. The relationship between the stressors and the impacts. Some stressors potentially contribute to several impacts, and many stressors can contribute to the same impact. The equivalency factors have been taken from Lindfors et al. (1995:1). For example, the reference stressor for Global warming is CO₂. The methods and equivalency factors for “Human toxicity” have to be further developed.

Quantitative relationships between the stressors and the impacts have been established, see e.g. Lindfors et al. (1995:1), Guinée et al. (1993:3; 1996) as well as Guinée and Heijungs (1995). Kandlikar (1996) discusses integration of scientific and economical aspects when defining the equivalency factors for greenhouse gases.

The approach based on equivalency factors enables to calculate the impact levels resulting from known stressor levels, and vice versa, to transform the requirements stated as certain impact levels to stressor level requirements. There are, however, two problems (Owens, 1996): 1. a linear relationship between the stressor and impact levels is assumed, and 2. no threshold levels exist, i.e. all stressor releases are assumed to lead to impacts. Moreover, in their study of environmental impacts of Finnish beverage packaging systems, Virtanen et al. (1995) concluded that as a whole, the method based on equivalency factors is not very well developed yet. For example, equivalency factors were either missing or highly controversial for several stressors. Defining the equivalency factors is, however, basic LCA research, which does not have to be done separately for each LCA study, but the cumulative information on the behaviour of different substances in the nature can be utilised.

5 Identify possible stressor and impact levels

The mere list of the impacts and the corresponding stressors is not enough, also the ranges of possible impacts have to be assessed. Without the knowledge of these impact ranges, it will be difficult to either set the target levels for the impacts or to consider the relative importance of the impact categories.

The stressor ranges can be studied by carrying out an LCA study for a set of products. Hypothetical products representing the best available and worst existing technologies can be generated to ensure the stressor ranges to contain all the possible outcomes. These stressor ranges would then be converted to the corresponding possible impacts by using equivalency factors.

Identification of the possible impact levels can create the need to reformulate the impact list. If the analysis shows that for some impact category the range is very small, i.e. irrespective of the technology used the impact would change only little, this impact could be felt obsolete, because it would not differentiate between the alternatives. If an impact will be removed from the index development, also stressors contributing only to this impact can be left out from the data collection. Removal of the impacts, however, has to be considered carefully, because after the removal the index does not provide any incentive to reduce that particular impact. Very harmful or toxic substances should be treated separately, e.g. within legislation. For example, if there is a strict legislative ban to use a particular substance, including it to the index is of little use.

6 Decide the type of the index

In principle, there are two ways to set up the evaluation scheme. Either the trade-offs between the different impacts are allowed or not. If they are not allowed, the product

has to reach the targets in all the impact categories simultaneously. Allowing trade-offs requires that the impacts are aggregated according to some aggregation rules and the target is expressed in terms of this aggregated impact, i.e. as one single target value. Then a “bad” performance in some impact category can be compensated by a “good” performance in the other(s). We call the approach not allowing trade-offs the “fixed” model and the approach allowing trade-offs the “flexible” model.

In practice, both approaches can exist so that for a set of impacts trade-offs would be possible, but for some other impacts there would be separate targets for each impact. For example, the index developers might want to control some toxic substances separately and not to allow trading-off them.

At this point, it is useful to distinguish between different types of trade-offs, because also the fixed approach offers possibility for trade-offs. Namely, if the whole product life cycle is taken into account, trade-offs are possible between different parts of the life cycle, e.g. increasing the CO₂-releases in the manufacturing could be compensated by reducing them in the raw-material and energy production, so that the total amount of CO₂ remains the same. Moreover, if equivalency factors are used for combining several stressors’ contribution to a set of impacts, trade-offs are possible between stressors that contribute to the same impact, e.g. CO₂ releases can be increased by the amount that contributes to global warming as much as the reduction of CH₄-releases. Besides these two types of trade-offs, the flexible model offers the possibility for trade-off between different impacts so that e.g. a certain increase of eutrophication could be compensated by a certain decrease in, say, global warming. This last type of trade-off differs from the earlier two by being more subjective, i.e. its quantification requires information on the preferences of the actual index developers.

7 Collect and model the required preference data

The fixed and the flexible models require different amounts of *preference information*, i.e. information on the decision makers’ values and priorities – the higher the level of aggregation of impacts, the larger the need for the information on the aggregation rules. One difficulty in the collection and modelling of this preference information can be that several interest groups or individuals with different views can participate in the index development.

In both the fixed and the flexible approach, the impact ranges are needed to make the target setting realistic – if only the current level of impacts would be known, the improvement requirements are without solid foundation.

7.1 Fixed model

In the fixed model, the level of acceptable environmental performance is stated for each impact. To be acceptable, the product has to reach all the target levels simultaneously. Implicitly, all the impacts are considered equally important.

When setting the targets, the decision maker can think how large an impairment from some highly desirable impact level she would be ready to accept. This reference level could be the zero impacts or based on assessment of impacts from using the best available technology (BAT). The BAT assessment can be part of the identification of the possible impact levels from an LCA study done earlier in the index development. The advantage of the zero level is that it can be defined without any uncertainty or costs. The obvious disadvantage is that it is usually unrealistic. Using BAT-level causes extra work and costs, but gives a more realistic starting point for the target setting. Quite often the BAT-level is relaxed by using the term BATNEEC (BAT not entailing excessive costs). It is used to stress that there are economical realities that cannot be ignored. Using BATNEEC, however, brings another source of subjectivity into the index development, because a cost that is deemed as excessive by one party could be regarded as acceptable by some other.

The starting point for target setting can also be the current impact level. For every impact, the required improvement from the current level is then stated. The current level is probably easier to estimate than the BAT-level, because it is based on existing practices and technologies of which there are data available. However, even large improvements do not necessarily lead to good environmental performance if the current level is exceptionally poor. Moreover, the target setting can be ambiguous if there is no idea of the lowest achievable impacts. The target setting as well as different impact levels are illustrated in Figure 4.

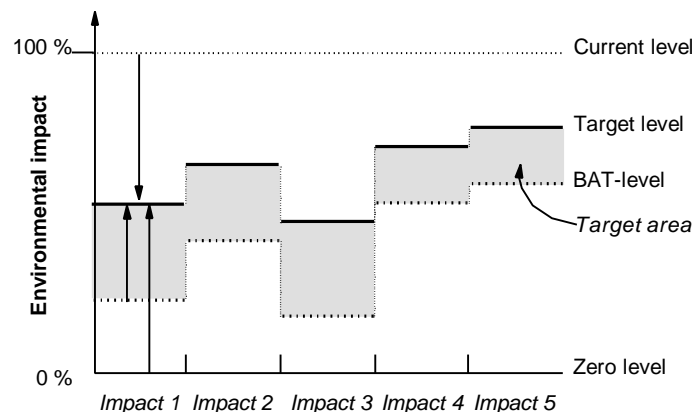


Figure 4. In the fixed model, a set of environmental impacts forms the basis of the index. To be acceptable, the product has to reach the target level in all the impacts simultaneously. The reference level can be the current, the best available or the zero impact level. For each impact, the current impact level has been normalised to 100 %.

7.2 Flexible model

In the flexible model, trade-offs between different impacts are possible. Bad performance in some impact category can be compensated by good performance in the others. The different environmental impacts are aggregated together. The level of acceptable environmental performance is announced with one value for the aggregated impact.

We consider the aggregated impact or total value of a product \mathbf{y} , represented by $\mathbf{y} = \{y_1, \dots, y_m\}$, where y_i is the outcome for the product on the i th impact. Value functions and impact category weights can be used to calculate the product's total value, $v(\mathbf{y})$, with linear additive value model: $v(\mathbf{y}) = \sum w_i v_i(y_i)$, where w_i is the weight of the i th impact category and $v_i(y_i)$ is the value of the product's outcome on the i th impact. In order for the linear additive model to be a valid representation of the preferences, all the combinations of the attributes (impacts) should be preferentially independent (Keeney and Raiffa, 1976). Attributes are preferentially independent if the preferences on the outcome on one attribute do not depend on the outcomes on the other attributes.

7.2.1 Value functions

A value function assesses a value for each outcome in the range considered for each impact. The range should cover all the possible outcomes. In defining the range, the worst existing and the BAT- or zero impacts level could be utilised. These can be obtained from the LCA study made earlier in the index development. Assuming less is better, the worst existing (i.e. the highest) impact level would be given the value 0, and the BAT- or zero level the value 1. Scaling the value functions to the interval [0,1] leads to special interpretation of the weights, which we shall discuss shortly.

The shape of the value functions explicitly indicates the decision makers' perception of the seriousness of the impact within the range. Several value functions are shown in Figure 5. A concave, decreasing value function indicates that the problem is not perceived to be very serious, since even large increases in the impact level receive considerably high values. A convex, decreasing value function indicates that even small increases from the best impact level result in considerably lower values. A linear value function indicates that changes are equally valued throughout the range. Even more complex value functions can be constructed. For example, if for certain impact category there is a threshold level below which no true adverse impact takes place, this can be modelled with a decreasing value function, which is concave for outcomes below the threshold and convex above it.

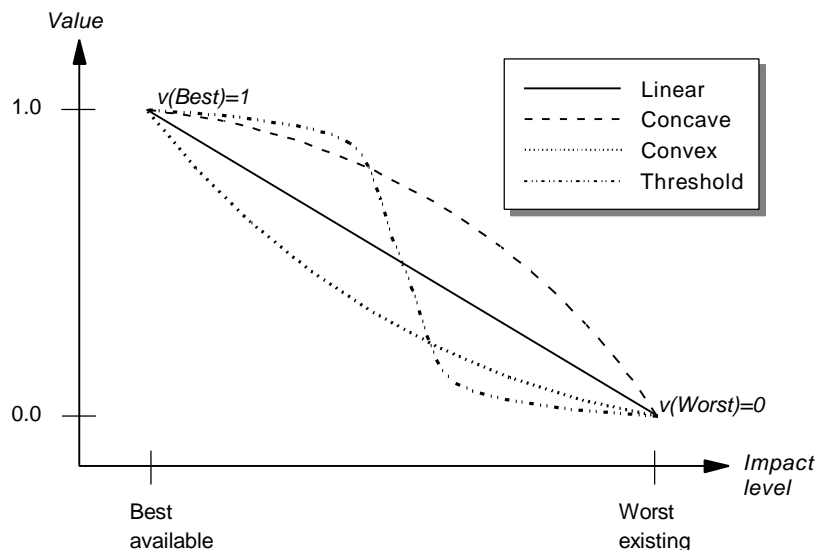


Figure 5. Linear, convex and concave value functions as well as a value function for modelling the threshold impact level.

For methods to elicit value functions, see for example Keeney and Raiffa (1976) or von Winterfeldt and Edwards (1986).

7.2.2 Environmental impact category weights

When the value functions are scaled to the interval $[0,1]$, the weight w_i represents the relative importance of moving from the worst to the best outcome in the i th impact. The weights are thus related to a specified change in the impact level and should never be interpreted without referring to this change. In the case of linear additive value model, the weights quantify the trade-offs between the impacts. Consider two impacts, i and j with weights w_i and w_j . If an increase D_i in the i th impact's value function exactly compensates a decrease D_j in the j th impact's value function, i.e. the total value $v(y)$ remains the same, then $D_i w_i = D_j w_j$.

The weights are often elicited by direct rating or by ratio statements. The resulting weights are normalised to sum to one, $\sum w_i = 1$. It is important to notice that these weights are elicited for each product group separately and for a specified change in the impact. Miettinen and Hämäläinen (1997) discuss the product group specific weight elicitation as well as the misconception of using general weights that remain the same even if the impact range would change.

There are possible behavioural biases in weight elicitation that should be taken into account, see e.g. Weber and Borchering (1993), Pöyhönen and Hämäläinen (1997:1) as well as Pöyhönen et al. (1997:1-2). Additionally, one should note that different weighting methods do not necessarily use the same scale and thus the weights elicited with different methods should not be taken as comparable. In particular, the differences between the multiple attribute value theory (MAVT) and the analytic hierarchy process (AHP) models should be made clear. For more details, see Salo and

Hämäläinen (1997), Hämäläinen and Salo (1997) as well as Pöyhönen and Hämäläinen (1997:2).

8 An example – Environmental labelling

We shall illustrate the approaches with a hypothetical environmental labelling example, where two environmental impacts and three stressors are considered. There are two main reasons for using a hypothetical example. First, a simple setting illustrates the index development steps and the differences between the two models better than a complex one. Second, the reliability and availability of equivalency factors is limited.

8.1 Stressor and impact data

Four products will be used in identifying the possible impact levels. These products are thought to be a representative sample of the environmental performance existing in the product group. Their performance is shown in Table 1. We stress that before arriving to the situation where all these data are available, first three steps of the index development have already been completed.

Table 1. Hypothetical environmental performance data for four product alternatives.

	x_1	x_2	x_3	$y(P_1)$	$y(P_2)$	$y(P_3)$	$y(P_4)$	BEI	WEI	BAI	WAI
y_1	1	2	5	61	44	54	60	44	61	31	76
y_2	4	6	1	46	84	69	78	46	84	40	98
$x(P_1)$	3	4	10								
$x(P_2)$	8	8	4								
$x(P_3)$	5	7	7								
$x(P_4)$	10	5	8								
$\min(x_i)$	3	4	4								
$\max(x_i)$	10	8	10								

x =Stressor; y =Impact; P =Product; BEI =Best Existing Impact; WEI =Worst Existing Impact; BAI =Best Achievable Impact; WAI =Worst Achievable Impact

In the rows labelled $x(P_i)$, the environmental stressor levels for each product are listed. Above that, the equivalency factors are shown. For each impact category y_i , there is one reference stressor, whose equivalency factor is 1. For example, for the impact y_1 , the reference stressor is x_1 . For y_1 , the equivalency factor for x_2 is two times and for x_3 five times larger than for x_1 . Each column labelled $y(P_i)$ shows the i th product's impact levels in the two impact categories. For example, product 2 has levels 44 and 84 in y_1 and y_2 , respectively. The last four columns labelled BEI , WEI , BAI and WAI contain impact levels that have been derived from the stressor and impact data. BEI (Best Existing Impact) is the minimum and WEI (Worst Existing Impact) the maximum impact level amongst the studied products. BAI (Best Achievable Impact) and WAI (Worst Achievable Impact) are the resulting impact levels when calculating the impacts using the minimum (BAI) and maximum (WAI) stressor levels. We select to use BAI and WEI levels in our example.

8.2 Fixed model

In the fixed model, the target levels for impacts y_1 and y_2 will be set. The question could be posed as “How large an impairment are we ready to accept from the *BAI*-level, i.e. from $y_1 = 31$ and $y_2 = 40$?” or as “How large an improvement we require from the *WEI*-level, i.e. from $y_1 = 61$ and $y_2 = 84$?” Each impact category would be considered separately. Let us assume that the targets are set to $y_1^* = 46$ and $y_2^* = 62$, i.e. the half-way between the *WEI*- and *BAI*-levels. To get an environmental label, the product must have $y_1 \leq 46$ and $y_2 \leq 62$, which expressed in terms of stressor level requirements is $x_1 + 2x_2 + 5x_3 \leq 46$ and $4x_1 + 6x_2 + x_3 \leq 62$. We note that none of the products used in the index development would be granted an environmental label!

8.3 Flexible model

In the flexible model, the value functions and the weights for the impacts have to be elicited. To keep the presentation simple, we use linear decreasing value functions for the impacts between the *BAI* and *WEI*-levels, i.e. $v_1 = (61 - y_1)/30$ and $v_2 = (84 - y_2)/44$.

In the weight elicitation, the impact ranges have to be explicitly taken into account by considering the changes in the impact levels from *WEI* to *BAI*, i.e. for y_1 from 61 to 31 and for y_2 from 84 to 40. The larger of the weights w_1 and w_2 can be found by asking the decision maker to select the more preferred from the two alternatives where one impact is at its best and the other at its worst level, i.e. $y^1 = \{BAI_1, WEI_2\} = \{31, 84\}$ and $y^2 = \{WEI_1, BAI_2\} = \{61, 40\}$, since $v(y^1) = w_1$ and $v(y^2) = w_2$. Let us assume that y^2 is preferred to y^1 and thus $w_2 > w_1$. The numerical values for the weights can be obtained for example by asking ratio questions. In this case, only one question is needed: “How many times more valuable do you consider the improvement in the y_2 level from 84 to 40 than in the y_1 level from 61 to 31?” Let us assume that the answer is three times. This implies $w_2 = 3w_1$. Together with the normalisation equation, $\sum w_i = 1$, we find the final weights to be $w_1 = 0.25$ and $w_2 = 0.75$.

Finally, let us assume that the critical value has been decided to be $v^* = 0.5$. The requirement for an environmental label would be stated as: $v = \sum w_i v_i(y_i) \geq v^*$ or $0.25(61 - y_1)/30 + 0.75(84 - y_2)/44 \geq 0.5$, which expressed as a stressor level requirement is $0.25 \times \frac{61 - (x_1 + 2x_2 + 5x_3)}{30} + 0.75 \times \frac{84 - (4x_1 + 6x_2 + x_3)}{44} \geq 0.5$. The follow-

ing table shows the values for the four product alternatives. Product P_1 fulfils the environmental label requirement.

Table 2. The values for the four product alternatives. The critical value v^* is 0.5.

	y_1	y_2	$v_1(y_1)$	$v_2(y_2)$	$v = \sum w_i v_i(y_i)$
P_1	61	46	0.00	0.86	0.65
P_2	44	84	0.57	0.00	0.14
P_3	54	69	0.23	0.34	0.31
P_4	60	78	0.03	0.14	0.11
w_i	0.25	0.75			
v_i	$(61-y_1)/30$	$(84-y_2)/44$			

8.4 Comparison of the fixed and flexible models

The fixed model implicitly holds all the impacts equally important, i.e. the impact weights are all the same ($w_i=1/n$, where n is the number of impact categories). By using these weights and the flexible model's value functions, we can translate the fixed model requirement into the corresponding flexible model critical value, $v^* = 1/n \sum v_i(y_i^*)$, where n is the number of impact categories and $v_i(y_i^*)$ is the value of the target outcome on the i th impact. This is in our example also 0.5 since for both impacts the fixed model target was set to the middle between the worst and the best levels, and a linear value function was chosen. Therefore $v_i(y_i^*) = 0.5$ and $w_i = 1/n = 0.5, i=1, 2$ from which it follows that $v^* = 0.5$.

The impact combinations where the fixed and flexible model requirements are met are illustrated in Figure 6. It can be seen that the area where the flexible model requirement is met is larger than the corresponding fixed one. This results from the possibility for trade-off between the impacts.

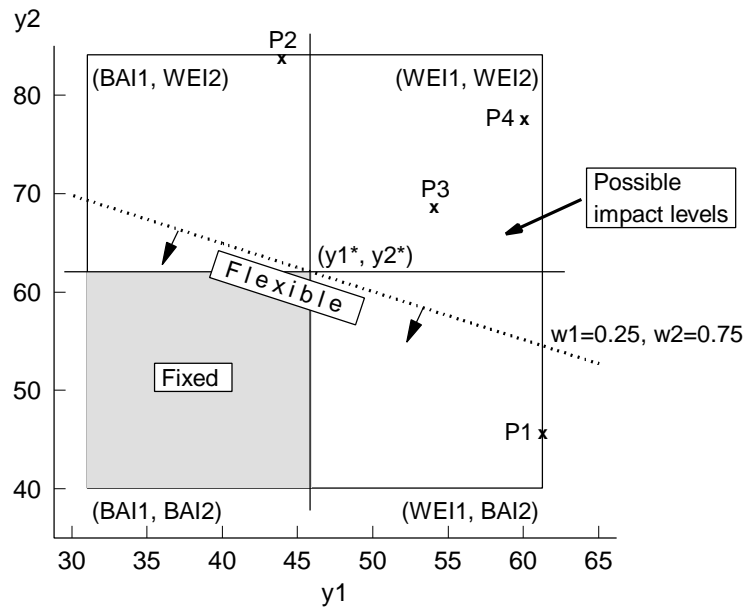


Figure 6. Fixed and flexible model targets in terms of impacts. The grey area is the area where both targets of the fixed model are reached. For the flexible model, the area is to the south-west from the dotted line.

9 Conclusions

We have presented a decision analytic, structured approach to develop indexes for environmental target setting. Two models were described: 1. the fixed model, where all the targets have to be reached separately, and 2. the flexible model, where bad environmental performance in some impacts can be compensated by having a good performance in the others. As the name suggests, the flexible model offers more freedom in reaching the target, but does this at the cost of increased need for preference information collection and modelling. In practice, both the fixed and the flexible models can be included in the index development so that for certain impacts, targets would be given separately, whereas the rest of the impacts would be aggregated and the target for them would be given in terms of the aggregated impact.

We also stress that there are two views involved: 1. the authorities who are using the environmental index for target setting, and 2. the companies, whose products are evaluated with the index. This distinction is operationalised by introducing environmental impacts and stressors and expressing the targets in terms of both.

Some issues related to the index development remain open. In the flexible model, the weighting of the impact categories is by no means an easy task – it typically requires combination of several decision makers' preference data into one single figure. A practical problem is the correlation between impacts. For example, reduction (increase) of the use of fossil fuels leads to reduction (increase) of global warming, which both could be included in the index. Therefore, the company optimising its operations subject to the targets set by the authority may not be able to take full advantage of a relaxation in one target.

An interesting further research topic is the analysis of the cost-efficiency of the fixed and flexible models. The hypothesis is that the flexible model offering more freedom to meet the requirement would typically lead to a more cost efficient solution for the company. This would justify the work needed to collect and model the larger amount of preference information needed compared to the fixed model.

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Appendix – A mathematical comparison of the two models

We consider the quantitative relationship between the environmental impacts and environmental stressors both in the fixed and flexible models. The following notation will be used and the following assumptions made:

$\mathbf{y}^T = \{y_1, \dots, y_m\}$ is the vector of environmental impacts. We assume that the environmental impacts obtain only non-negative values, $y_i \geq 0$, $i = 1, \dots, m$. Without loss of generality, we assume for each impact that less is better.

$\mathbf{Y} = \{\mathbf{y} \in \mathbb{R}^m \mid \mathbf{y} \geq \mathbf{0}\}$ is the set of impact vectors forming the impact space, i.e. the non-negative orthant of \mathbb{R}^m .

$\mathbf{x}^T = \{x_1, \dots, x_n\}$ is the vector of environmental stressors contributing to the impacts. We assume that the environmental stressors obtain non-negative values, $x_j \geq 0$, $j = 1, \dots, n$.

$\mathbf{X} = \{\mathbf{x} \in \mathbb{R}^n \mid \mathbf{x} \geq \mathbf{0}\}$ is the set of stressor vectors forming the stressor space, i.e. the non-negative orthant of \mathbb{R}^n .

We assume that the relationship between the environmental stressors and the environmental impacts can be modelled using the equivalency factors and thus expressed as $\mathbf{y} = \mathbf{A}\mathbf{x}$, where

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdot & a_{1n} \\ \cdot & \cdot & \cdot \\ a_{m1} & \cdot & a_{mn} \end{bmatrix}$$

is the matrix of the equivalency factors. The element a_{ij} expresses the relative contribution of the j th stressor, x_j , to the i th impact, y_i . The i th row of \mathbf{A} is denoted \mathbf{a}_i . We assume that all a_{ij} 's are non-negative.

In the fixed model, the authority states that the highest acceptable impact levels are $\mathbf{y}^{*T} = \{y_1^*, \dots, y_m^*\}$. The i th requirement, $y_i \leq y_i^*$, is mapped into a halfspace $\mathbf{a}_i \mathbf{x} \leq y_i^*$ in \mathbb{R}^n . The intersection of this halfspace and the stressor space \mathbf{X} is the area where the i th requirement is met. Since all the m requirements have to be met, the target area is the intersection of \mathbf{X} and the m halfspaces, $\mathbf{a}_i \mathbf{x} \leq y_i^*$, $i = 1, \dots, m$. The target areas in the impact space, \mathbf{Y} and in the stressor space, \mathbf{X} are illustrated in Figure 7.

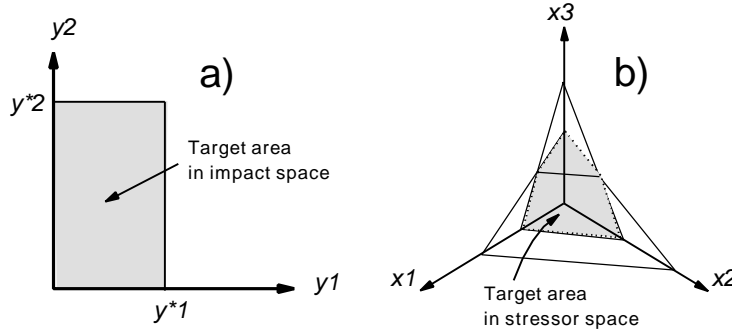


Figure 7. Target areas in a) the environmental impact space, \mathbf{Y} , and b) the environmental stressor space, \mathbf{X} .

In the flexible model approach, the requirement for an acceptable level of environmental performance is expressed in terms of the aggregated impact. In calculating the value of this eco-index, the value functions and weights for each environmental impact are needed. We assume a linear value function, $v_i = \mathbf{a}_i + \mathbf{b}_i y_i$. Two outcomes in the i th impact, the worst one, y_{i-} , such that $v_i(y_{i-}) = 0$ and the best one, y_i^+ , such that $v_i(y_i^+) = 1$ determine the intercept \mathbf{a}_i and slope \mathbf{b}_i . From this follows (less is better):

$$\mathbf{a}_i = \frac{y_{i-}}{y_{i-} - y_i^+} \geq 1 \text{ and } \mathbf{b}_i = \frac{-1}{y_{i-} - y_i^+} < 0, \text{ because } y_{i-} > y_i^+ \geq 0$$

In case of linear additive value model, the requirement that the eco-index should be at least v^* can be expressed as:

$$\sum_{i=1}^m w_i (\mathbf{a}_i + \mathbf{b}_i y_i) \geq v^* \Leftrightarrow -\sum_{i=1}^m w_i \mathbf{b}_i y_i \leq -v^* + \sum_{i=1}^m w_i \mathbf{a}_i, \text{ which is a halfspace in } \mathbb{R}^m. \text{ The}$$

intersection of this halfspace and \mathbf{Y} is the area where the product satisfies the requirement. The halfspace is certain to have a non-empty intersection with \mathbf{Y} , because

$$-v^* + \sum_{i=1}^m w_i \mathbf{a}_i \geq 0. \text{ This follows from } v^* \in [0, 1], \mathbf{a}_i \geq 1 \text{ and } \sum w_i = 1, \text{ since then}$$

$$\sum_{i=1}^m w_i \mathbf{a}_i \geq \sum_{i=1}^m w_i \times 1 = 1 \geq v^*.$$

The target area in stressor space, \mathbf{X} , can be expressed as follows:

$$\sum_{i=1}^m w_i (\mathbf{a}_i + \mathbf{b}_i y_i) \geq v^* \Leftrightarrow \sum_{i=1}^m w_i (\mathbf{a}_i + \mathbf{b}_i \sum_{j=1}^n a_{ij} x_j) \geq v^* \Leftrightarrow -\sum_{i=1}^m w_i \mathbf{b}_i \sum_{j=1}^n a_{ij} x_j \leq \sum_{i=1}^m w_i \mathbf{a}_i - v^*,$$

which is a halfspace in \mathbb{R}^n . The intersection of the halfspace and \mathbf{X} is the area where the product satisfies the requirement.

The target areas in different spaces are illustrated in Figure 8.

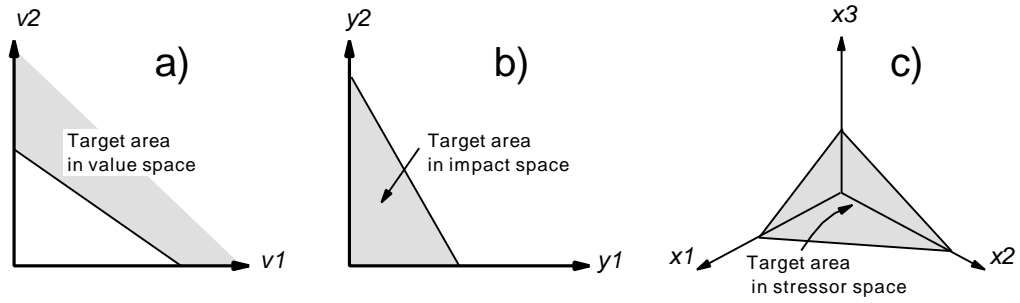


Figure 8. Target areas in a) value, b) impact, \mathbf{Y} and c) stressor, \mathbf{X} spaces.