Sustainable Development: How To Weigh Both Economical and Ecological Cost? A New Strategy for a Combined Optimization

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Sustainable development attempts a combined optimization of ecological, economical and social development. One task, then, is to measure progress in these terms, i.e. to weigh, e.g. economical against ecological advantages. We have developed and tested a method that combines at least the most essential criteria of ecological and economical development, i.e. the ecological cost derived from ecobalance studies and the economical cost derived from life-cycle cost calculations. The method consists of improving lower-cost products as long as they are cheaper than their alternatives. These improved products, which cost the same or less, are then compared in an ecobalance study with the alternatives. In many cases these improved products show by far the best ecological results and cost no more than the alternatives. They thus have the highest optimization potential both from an economical and ecological point of view. A strategy that strives towards sustainable development optimizes rare economical and ecological resources in an ecoefficient way. One formulation of such a strategy: Use lower-cost products and improve them by using all or part of the price difference relative to their alternatives; these optimized products are very often much better when comparing ecobalance results, and not more expensive than their alternatives. This is shown to be the case for PVC windows compared both to wood and aluminum windows. An alternate method, the monetarizing of ecological impacts, is briefly discussed.

INTRODUCTION

Sustainable development is based on a sane and joint ecological, economical and social development, sometimes called the "triple bottom line of sustainable development." These three pillars of a sustainable development are widely accepted, though there is a debate as to whether ecological development is the most eminent and central pillar, or whether all pillars are of equal importance.

One task is to quantify progress in each of these areas: This can be realized rather easily. The economic impact of products or use-systems is measured (to a large extent) by a life cycle (economical) cost analysis (LCCA), if necessary after internalization of external costs.[1] Ecological impact is calculated by methods such as risk assessments and life cycle ecological analyses (LCEA). Social impact is calculated by methods such as workers' wealth (accidents, income etc.) and others. Steps toward sustainability consist in lowering:

- life-cycle costs, thus lowering the economic impact
- life cycle ecological impact (e.g. energy demand and CO_2 emissions)
- accident numbers, or, increase workers' qualifications for a positive social development. The social development factor is not discussed in this work.

The second task is to compare both ecological and economical impacts. If, in a comparison, both economical and ecological results are better for product A than for product B, then product A is better than B (in terms of LCCA and LCEA). It is not clear how two products compare where A has better economical and B better ecological results.

One possibility is called monetarizing of ecological impacts (1)—a widely accepted goal, but at the moment still not practical because of some difficulties (see section **4**). We have developed a different, straightforward approach, and use this as a new strategy in ecoefficient optimization (2).

We start with two products, A and B, serving the same demands. A should be a low-cost product compared to B (in our example A is a PVC window, B a more expensive wood or aluminum window). We then

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[1]"External" cost can be cost paid by the public (e.g. subventions, ...); if this cost would be paid by the one responsible for it, it would be "internalized."

improve the low-cost product A (call this improved product A_{imp}). By this optimization A_{imp} becomes more expensive than A. We look for optimizations that leave the cost of A_{imp} lower than or equal to that of B. Then we calculate ecobalance results for this improved product A_{imp}. If, then, ecobalance results of product A_{imp} have been improved over those of B, then A_{imp} and B are comparable in economical terms, but A_{imp} is better in terms of ecological cost. Taken altogether, A_{imp} is then more sustainable than B.

Both resource types—"economy" and "ecology"—are scarce; we do not have enough "money" or enough "environment." The strategy shown here for a joint optimization is: "Use cheaper products and use (part of) the money saved in this way to improve the ecological impact of this cheaper product. In many cases this will result in the most ecologically attractive product."

This strategy is detailed below in the case of windows. The calculations used for this work reflect the middle and north European situation, i.e. energy demand to maintain a moderate temperature in houses results from heating in winter and not—as might be the case in hotter climates—from cooling in summer.

1. (ECOLOGICAL) LCEA RESULTS FOR WINDOWS

There are two new European window ecobalance studies (3, 4). Apart from the lack of a "critical review" in both of them, they are consistent with EN ISO 14040. Some results:

1. Differences due to different materials (PVC, wood, aluminum) are not very big (exemption CO_2, see below).
2. PVC never scores worst and sometimes best.
3. Wood as a renewable material consistently scores better in CO_2 emissions (today's energy supply) compared to PVC by some 50 kg CO_2 per window.
4. Most important for window systems is the use phase: Energy demand (and related emissions) due to heating during winter is much higher than that due to manufacture of the window. If the sun is shining during winter, the energy gain can be much higher than the sum of all energy demands over a complete life cycle including a use period of 40 years. Thus, three ways to optimize can be stated: 1) Reduce heat loss through profile; 2) Reduce heat loss through glass pane; 3) Increase light throughput through glass pane.

Figure 1 shows results (upper part: only the profiles) from the most recent LCEA (4) for the most important ecological criteria (note that both toxicological criteria —human and ecotox—are still much debated and need further development). The foregoing statements 1, 2 and 3 can be deduced from this figure.

The lower part of *Fig. 1* shows how much manufacturing of the glass pane, window assembly and recycling contributes. Adding very similar values for this onto results of the upper figure decreases the relative differences shown in this lower part.

Figure 2 shows results for energy demand and CO_2 emissions of the whole life cycle for a good standard PVC window only. The most important assumptions (2): K-value of the glass pane and the PVC profile is 1.4; glass fills 75% of the window area. Use phase includes heat losses and energy gain during winter, which are much more important compared to production and recycling of the window.[2] The foregoing statement 4 can be deduced from this figure.

The left side of *Fig. 3* shows the same results as *Fig. 2* (i.e. including use phase, only energy demand and CO_2 emissions) but also for wood and aluminum windows with the same good standard glass pane. The above-mentioned CO_2 advantage of a wood vs. a PVC framed window can still be seen. Aluminum windows score worse because heat loss through the Al profile is consistently higher than through wooden and PVC profiles.

(Positive results in *Figs. 2* and *3* are perhaps not self- explanatory, since ecobalance results are normally "negative" numbers, i.e. they have a negative impact upon the environment. Positive numbers indicate a positive impact on the environment, i.e. the overall energy gain is greater than overall energy loss, and more CO_2 is conserved than emitted.)

2. (ECONOMICAL) LCCA RESULTS FOR WINDOWS

Prognos AG, Basel, has calculated LCCA for PVC, wooden and Al windows (v). We adjusted the results to some specific conditions of the underlying ecobalance study (4); this does not critically affect the results of this paper. The LCCA results are included in *Fig. 3*. Some statements on these cost results:

1. LCCA shows much lower economical costs for PVC windows compared with both wooden and Al windows. Higher results from a LCCA for wooden windows come mainly from painting, for Al windows from higher investment cost.
2. Heating or recycling (economical) costs are included but are quite low and hardly influence the results.

3. COMMERCIAL OPTIMIZATION POSSIBILITIES FOR WINDOWS

There are commercial solutions to the optimization possibilities explained above for all materials.

- The heat loss of the profiles can be reduced from "normal" k-values of 1.4 to around 0.7 by using multi-chamber profiles, or better still, by foam-filled hollow chambers (in the case of PVC profiles).
- The heat loss of glass panes can be reduced from k-values of around 1.1 down to 0.7 by using triple glazing instead of double-glazed systems.

[2] Results have been averaged over a house with more windows looking to the south than to the north.

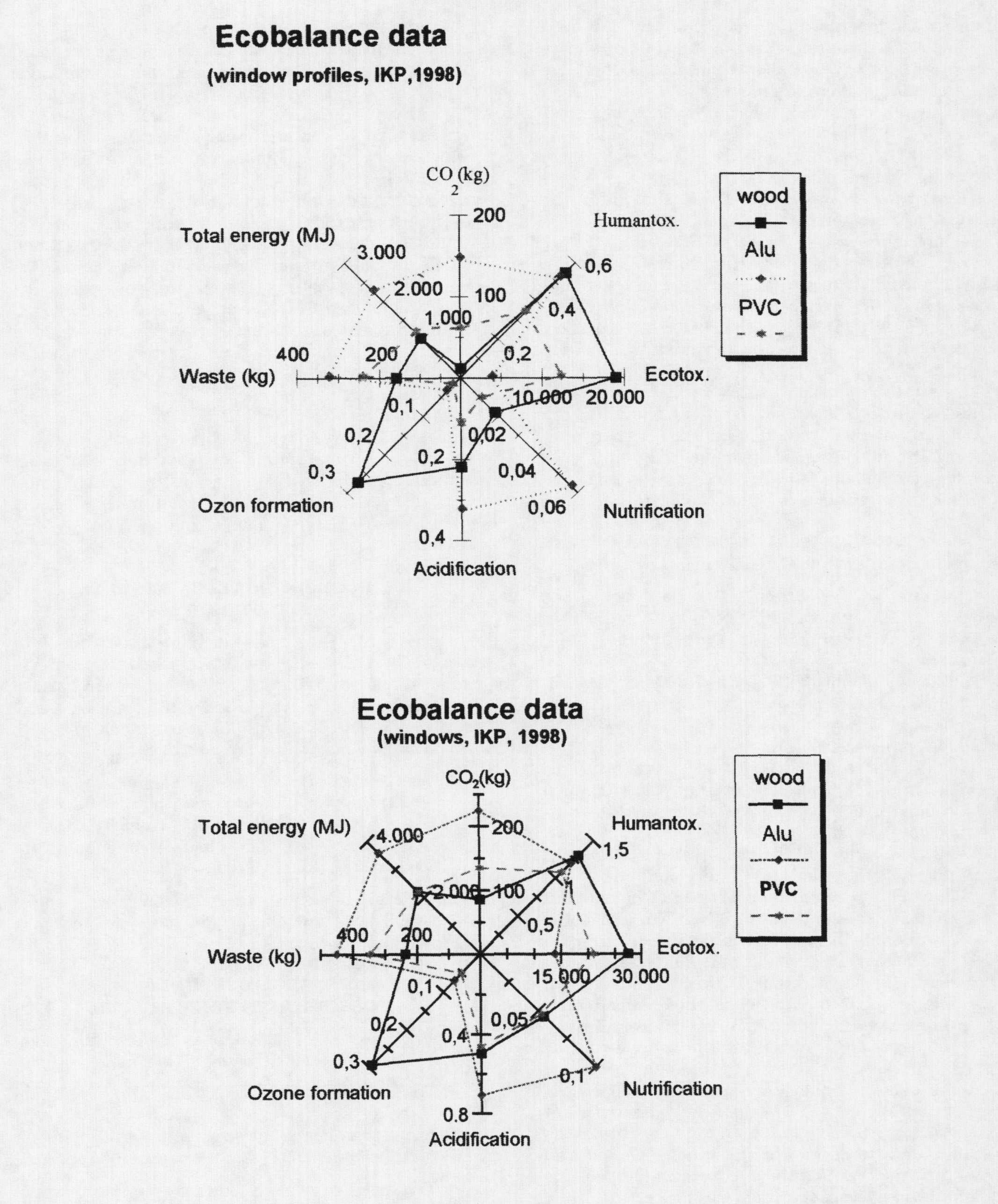

Fig. 1. Results of ecoprofile work: Upper Part: only profiles. Lower Part: whole window including glass pane, recycling etc.

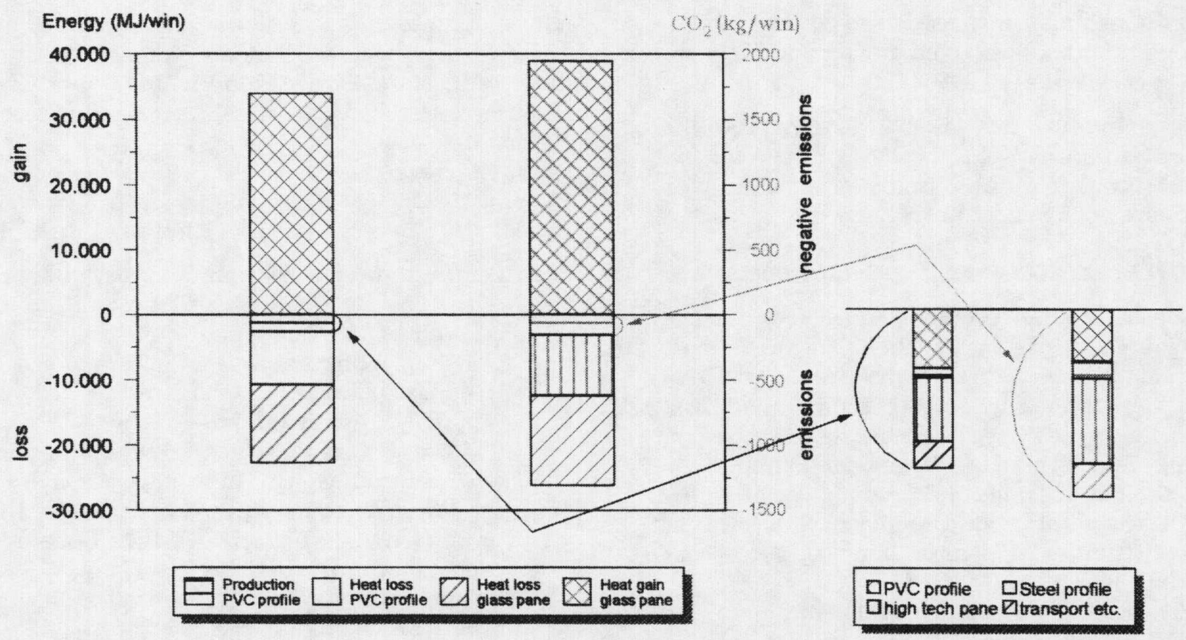

Fig. 2. Window ecoprofile work: Contribution of different life cycle stages to energy demand and CO_2 emissions.

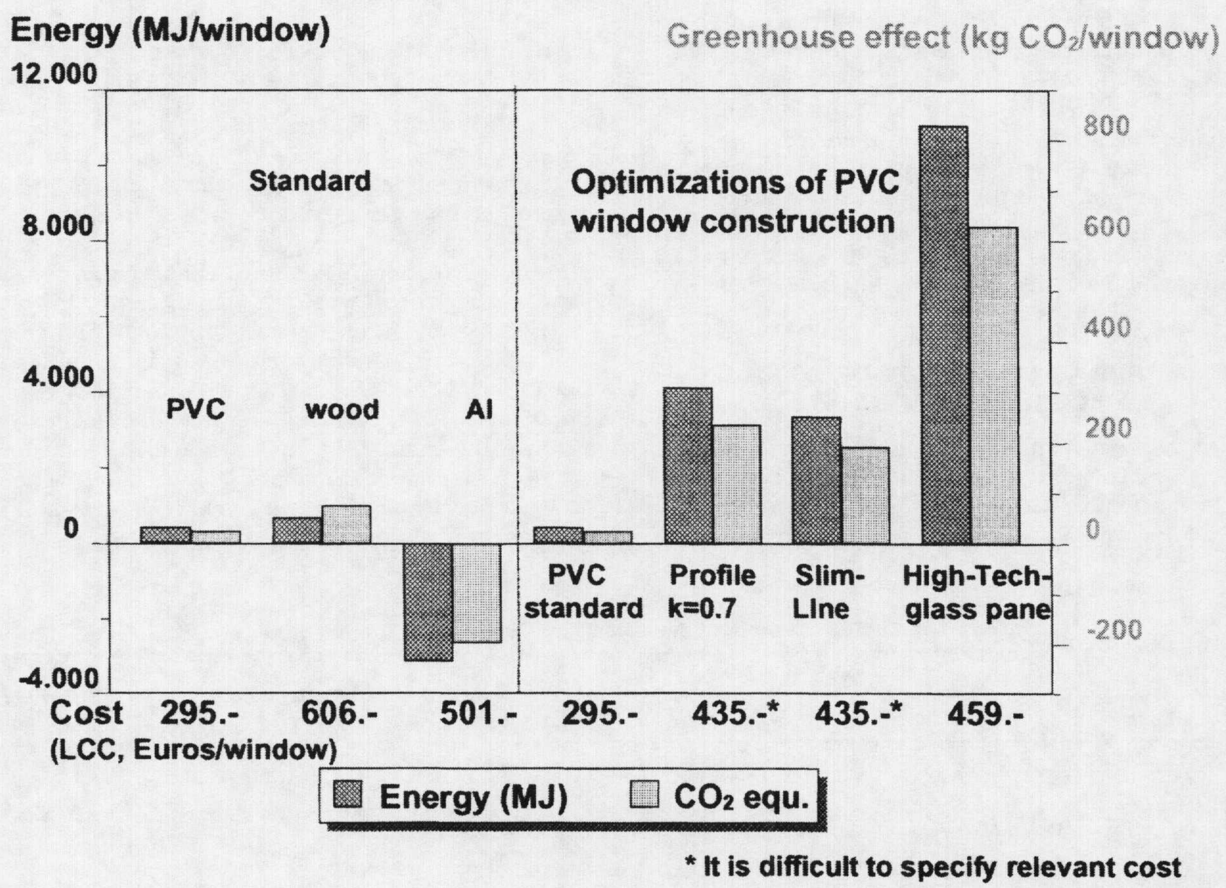

Fig. 3. LCEA and LCCA results for three standard windows (left side) and different optimization possibilities (right side).

- Light throughput is increased (high g-value) by constructing windows with slim profiles and therefore greater glass pane areas.
- There are many other possibilities to improve the system "windows," e.g., by using forced air exchange together with preheating of fresh air, etc., which are not discussed here.

4. MONETARIZING OF ECOLOGICAL IMPACTS

Emissions and other ecologically negative impacts principally create costs that at the moment are most often not paid by the producer of these emissions. This cost can be quantified by several methods, e.g., cost to compensate the damage of emissions or cost to reduce them. If the sum of these costs for all impacts is added to the market price of a product, it can be determined if a special product would have a lower or higher cost ("sum of economical and ecological cost") compared to alternatives.

Recently, several ecobalance practicing institutes have used this methodology (1). The cost numbers in such studies for emissions of CO_2, NO_x, SO_x, CH_4, etc. are shown in *Table 1*. These cost numbers vary by very large factors, according to the methodology with which they were calculated: CO_2 cost e.g. varies from 3.9 to 139 Euro/t of CO_2 (1) (cost to repair damage by climate change) up to 190 Euro/t of CO_2 (6) (cost to decrease CO_2 emissions to a worldwide acceptable value). To quantify other costs, e.g., of a rare type of a landscape, will be still more difficult if not impossible. As a result, the methodology of monetarizing ecological impacts still needs to be greatly improved.

One result nevertheless is noteworthy: Even the highest CO_2 result of 190 Euro/t of CO_2 does not influence the LCCA results in section **2**, since 50 kg CO_2, by which wood is better than PVC, costs at most 10 Euro/window. This decreases the advantage in LCCA of PVC windows only slightly (3–4%).

5. COMBINED OPTIMIZATION OF ECOLOGY AND ECONOMY OF WINDOWS

Figure 3 shows results (left side) for three different standard windows and (right side) results achieved by using PVC windows with an optimized high-tech glass pane and other improvements as previously discussed. These optimized PVC windows are all more expensive than the standard PVC window, but are less expensive than both standard wooden or aluminum windows. Their ecological data are much better than those of all other windows.

Considering the case where there are equivalent products with lower and higher cost, a strategy for ecoefficient optimization can be formulated as follows:

1. Optimize the low-cost product A with all or part of the cost difference between A and the higher-cost alternative B.
2. Check if optimization was successful ecologically by comparing ecobalance results of improved product A_{imp} with alternative B.
3. If these results show better ecological performance of product A_{imp}, and it's economical costs are lower or equal to those of product B, then product A_{imp} is better than B in terms of both ecobalance and economical cost.
4. Use improved product A_{imp} instead of unoptimized product A or product B.

Since optimization is the primary goal of ecological (or economical) balances, we propose making ecobalance comparisons based on equal (or near equal) cost after the low-cost system has been optimized. This differs from current practice today where products are compared based on their technical equality.

6. CAN THIS STRATEGY ALSO BE APPLIED TO OTHER SYSTEMS?

Another example where this strategy can be readily applied is "heat insulation." LCCA shows that insulating sheets made from mineral fibers or PS/PU foams are much cheaper than, for example, insulating sheets made from sheep wool or cork. By contrast, LCEA (manufacturing only) shows that insulating sheets made from sheep wool are slightly better in terms of CO_2 emissions or energy consumption than, for example, PS foams. These differences from manufacturing LCEA are already lower than what can be saved in the first year. An ecoefficient strategy would heavily increase the insulating thickness with the cheaper PS foam. The new LCEA would show a much better ecological performance of the thicker PS foam still being the cheaper solution.

Table 1. Cost Sets in Euro/t for Ecological Impacts Used in Different Studies.

Ecol. Impact	AEA study (1) Best estimate	AEA study (1) Low estimate	AEA study (1) High estimate	GUA study (1)	UBA study (6)
CO_2	19	4	139	63	190
SO_2	9200	1300	27,000	2544	
NO_x	10,000	1100	30,000	2035	8700
PM_{10}	17,000	1900	50,000		
Cd	67,000	6700	120,000	356,100	
Pb	10,000	6700	15,000	71,200	
Dioxin	290,000,000	29,000,000	520,000,000		
CH_4	210	43	1600	1550	

Other optimization possibilities increase the lifetime of products, decrease the weight in car components, etc. Longer lifetime clearly improves ecobalance results, as does lowering the weight of car components, etc.

Using cheaper products and utilizing part of the money saved for optimization—this concept can be applied to all types of systems. In an extreme case, the system could be the two products A and B (B being more expensive) and a product C, which is not necessarily related to the products A and B. We take all or part of the cost difference between A and B and use it to optimize C into C_{imp}. Then we check whether, by our measures, the overall economical and ecological impact is lower for both products A and C_{imp} compared to B and C. If this is true, we say that product A has a higher sustainability potential.

7. HOW TO USE THIS POTENTIAL FOR ECOEFFICIENT ACTIONS?

In the foregoing examples, the optimized systems are much better ecologically than all other systems. But they are cheaper than the alternative systems only and not cheaper than the same but nonoptimized system.

What incentives can trigger a move towards such optimized ecoefficient systems?

1. Information from industry, from consumer, municipal and governmental organizations will be most important.
2. On the basis of such quantitative information, consumers could be "rewarded" by municipal or other organizations based on the amount of CO_2 savings, and not on the of amount of money invested, as is practiced sometimes.

Suggestions for other incentives or critical remarks will be highly appreciated.

LIST OF ABBREVIATIONS

Cd	:	Cadmium
CH_4	:	Methane
CO_2	:	Carbon dioxide
NO_x	:	Nitrogen oxides
Pb	:	Lead
PM_{10}	:	Particles with diameter less 10 micron
SO_x	:	Sulfur oxides
PS	:	Polystyrene
PVC	:	Polyvinylchloride
PU	:	Polyurethane
LCEA	:	Life cycle ecological analysis
LCCA	:	Life cycle (economical) cost analysis
k-value	:	Coefficient of heat flow ($W/(m^2*K)$)

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