The model of the
Eco-costs / Value Ratio

A new LCA based decision support tool

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Joost G. Vogtländer

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Proefschrift

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Preface and Acknowledgements

Ever since 1990, when I was appointed as group vice president for 'Quality, Productivity, and Logistics' of a big multinational in the packaging industry (Bührmann Tetterode, KNP BT after the merger in 1993), I had a vague, but growing, unease about the environmental policy on packaging in The Netherlands. It was not my primary responsibility since a colleague was responsible for 'Environmental issues and Innovation'. I, as a citizen with common sense, had not the impression that the problems were being tackled in an effective and efficient way. Moreover, as a business man I had the feeling that we were missing opportunities. 'Short Termism' was the leading attitude in the policy making of the government as well as the industry. This resulted in negotiations where "win-win" solutions appeared inconceivable. The outcome of the negotiations itself seemed to be more important than finding the right approach to minimize the environmental burden of packaging. Everybody involved was well-intentioned, but there were no models and theories available to unravel and understand the complex problems. It did not seem possible to bring the business interest into line with the environmental constraints.
Many internal discussions were held within KNP BT Packaging on the issue of the environment. The aim of the board of directors was to create a competitive edge on the subject by means of Total Quality Management and Innovation. However, the environmental issues appeared to be a threat rather than an opportunity for most of the managing directors of the operating companies. Economy and ecology appeared to be in conflict with each other, so 'reconciliation' seemed to be the maximum achievable instead of a more positive strategic approach.

In 1996 I became interim managing director of a small consultancy company in the field of (macro) economics on environmental issues, and was confronted with similar problems. The results of Life Cycle Analyses appeared highly sensitive for the chosen systems and boundary limits. This is maybe a 'fact of life', however, the conclusions of the analyses were heavily influenced as well. LCAs of service systems appeared hardly possible with the standard methodology. Analyses were ad hoc, complex, only understood by specialists, and not understood by the people who had to take the strategic decisions. So it is doubtful whether these LCAs have had any influence on the real strategic business decisions.

A third confrontation with the complexity of the issue of sustainability took place in 1997, during a consultancy assignment in a special redesign project of the HSL-Zuid (the High Speed railway Line from Amsterdam to Paris, via the "green heart" of Holland). At that moment, hardly any Dutch citizen was still enthusiastic about the result of 'political bargaining' and 'Not-In-My-Back-Yard' discussions. The basic idea of 'people out of the plane into the train' seemed to be a good one, but was the balance lost between economy and ecology? 'Guts feel' was mastering the discussions: who had any understanding of the complex issues in order to deal with the 'ecology versus economy' dilemmas?

The vague unease of 1990 had changed now into a strong urge to develop a model that could support strategic decisions of companies and governments. A model that provides the citizen/consumer, the business manager and the politician with sufficient well-structured information on which to base their (strategic) preferences.
Since, who does not want to contribute (even if that contribution is small) to the development of the 'sustainability' of this world for the benefit of our children and grandchildren? That is how the plan was born to write this thesis.

* Edward de Bono:
"you cannot see what your mind is not prepared for"

Prosperity: a fragile balance between economy and nature

On Venice*:

" . . . . . . Almost every winter for many years, large parts of the city have become flooded. Indeed, this is becoming an even more frequent occurrence. It is due to the subsidence of the entire area under and around the lagoon, which in turn has been caused by the abstraction of groundwater by industry and agriculture in the surrounding region. . . . . The requirement for such water can only be countered by the construction of a major new freshwater supply line from the lower Alps to Venice. The specific geological characteristics of the area suggest that the plans to raise the city from below by pumping in water under pressure are unrealistic. . . . . . The rising local seawater level has caused damp in the walls of many buildings, which has damaged many paintings and frescos. Air pollution, caused by a chemical industry which is not adequately supervized, has caused irreparable damage to sculptures and buildings. Much has already been lost and unless action is taken soon, at least half of the art treasures which remain will also be lost within the next forty years. . . . . . The problems faced by Venice are primarily of a social nature. Tourism does not provide sufficient revenue for the winter months. Young people prefer to live on the mainland, where they can have their own car parked outside the front door rather than having to walk or rely on boats. Houses in Venice itself are rapidly decaying. New sources of revenue must therefore be found in order to make the old city an attractive place to live in once more. . . . . "

From: *Grote Winkler Prins Encyclopaedia*, seventh edition, 1974, (in translation).

It is with some hesitation that I selected the above to serve as the introduction to this thesis. Is it relevant to the topic of sustainability and eco-efficiency? Is the picture presented a realistic one? Can the same phenomenon, or one broadly similar, also be seen elsewhere? The situation described presents many facets of the same reality. However, the significant characteristic is that it is impoverishment which is leading to decay: there are insufficient funds for maintenance, let alone for new measures such as the construction of a drainage system. Faced with the threat of greater unemployment, the government allows industry and agriculture to place an unwarranted burden on the local environment. (This is a dilemma we have seen not only in Eastern European countries and the developing countries, but also in the Netherlands. Here too, numerous instances can be cited in which the government has succumbed to pressure from various lobby groups and has failed to take appropriate measures, resulting in harm to the environment).

* The cover (Palazzo Capello Malipiero, La Volta del Canal, Venice): "Water is a boon in the desert, but the drowning man curses it" (English proverb)

For Venice, the prospects are now more encouraging than was the case twenty years ago:
- the Italian government has now prohibited any further abstraction of water by industry
- the historic city centre is being refurbished with international assistance
- economic activity is being developed in the service sector, located in the city cetre.
The new challenge, however, is to withstand the ever growing mass of tourists who are attracted by inexpensive travel arrangements, and to withstand the increased frequency of flooding.

The policy to be adopted is clear: the city can only survive if it is has sufficient economic strength (i.e. ongoing prosperity) to be able to stop the ecologically harmful activities, construct sewers, and perhaps construct a seawater barrier which is normally open but can be closed at high tides.
At the same time, strong economic growth must not itself result in any additional environmental impact (e.g. de-linking of economy and ecology)

It would seem that in our modern world, the concept of 'sustainability' has become quite complex. It now goes beyond the encouragement of an alternative 'simpler' lifestyle, of the type still best illustrated by the familiar anecdote concerning Diogenes: when Alexander the Great promised him anything whatsoever he might desire, Diogenes merely asked Alexander to stand aside out of the sun.

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Summary

The model of the Eco-costs / Value Ratio

The Eco-costs / Value Ratio, EVR

The basic idea of the EVR (Eco-costs/Value Ratio) model is to link the 'value chain' (Porter, 1985) to the ecological 'product chain'. In the value chain, the added value (in terms of money) and the added costs are determined for each step of the product "from cradle to grave". Similarly, the ecological impact of each step in the product chain is expressed in terms of money, the so called eco-costs. See Figure A.

| **Value :** | value | + △ value | + △ value | + △ value | + △ value | + △ value | **= Total value** |

| **Costs :** | costs | + costs | + costs | + costs | + costs | + costs | **= Total costs** |
| **Eco-costs:** | eco-costs | + eco-costs | + eco-costs | + eco-costs | + eco-costs | + eco-costs | **= Total Eco-costs** |
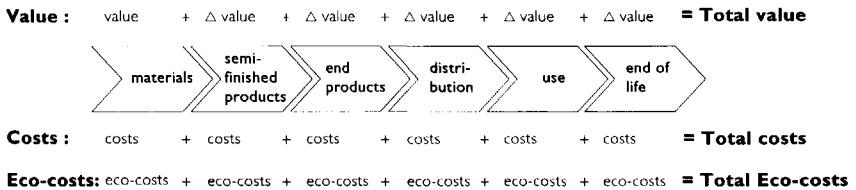
Fig. A: The basic idea of combining the economic and ecological chain: "the EVR chain".

The eco-costs are 'virtual' costs: these costs are related to measures which have to be taken to make (and recycle) a product "*in line with earth's estimated carrying capacity*" [a]. These costs have been estimated on the basis of technical measures to prevent pollution and resource depletion to a level which is sufficient to make our society sustainable. Since our society is yet far from sustainable, the eco-costs are 'virtual': they have been estimated on a 'what if' basis. They are not yet fully integrated

[a] In 1995, the World Business Council for Sustainable Development (www.wbcsd.ch/eurint/eeei.htm) described the role for industry in their definition of eco-efficiency as:
"the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity, through the life cycle, to a level at least in line with earth's carrying capacity."

in the current costs of the product chain (the current Life Cycle Costs). The ratio of eco-cost and value, the so called Eco-costs / Value Ratio, EVR, is defined in each step in the chain as:

$$EVR = \frac{eco\text{-}costs}{value}$$

For one step in the production+distribution chain, the eco-costs, the costs and the value[b] are depicted in Figure B.
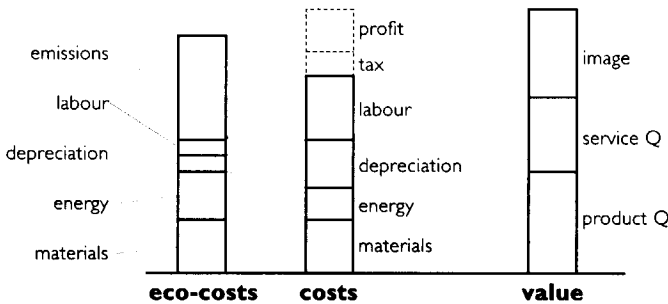
Fig. B: The decomposition of "virtual eco-costs", costs and value of a product.

The five components of the eco-costs have been defined as 3 'direct' components plus 2 'indirect' components:
✓ virtual pollution prevention costs, being the costs required to reduce the *emissions* of the production processes to a sustainable level (Vogtländer et al., 2000)
✓ eco-costs of *energy*, being the price for renewable energy sources
✓ *materials* depletion costs, being (costs of raw materials) $* (1-\alpha)$, where α is the recycled fraction
✓ eco-costs of *depreciation*, being the eco-costs related to the use of equipment, buildings, etc.
✓ eco-costs of *labour*, being the eco-costs related to labour, such as commuting and the use of the office (building, heating, lighting, electricity for computers, paper, office products, etc.).

Based on a detailed cost-structure of the product, the eco-costs can be calculated by multiplying each cost element with its specific Eco-costs / Value Ratio, the EVR. These specific EVRs have been calculated on the bases of LCAs. Tables are provided for materials, energy and industrial activities.

[b] *Within the business chain, the value equals the market price. From the consumers point of view the value equals the 'fair price' (Gale, 1994). Note: in the business chain, the cost for the buyer is the value for the seller.*

In the EVR model Eco-efficiency is defined as:

$$\text{eco-efficiency} = \frac{(value - eco\text{-}costs)}{(value)} \text{ , or eco-efficiency} = 1 - EVR$$

Note that the eco-efficiency is:
- negative when the eco-costs are higher than the value, or where EVR > 1
- 0% when the eco-costs are equal to the value, or when EVR = 1
- 100% when there are no eco-costs, or when EVR = 0.

(See section 3)

The pollution prevention costs

The aforementioned pollution prevention costs are being calculated in four steps:
1. LCA calculation according to the current standards (ISO 14041)
2. Classification of the emissions in 7 classes of pollution
3. Characterization according to characterization multipliers as used in e.g. the Eco-indicator '95, resulting in 'equivalent kilograms' per class of pollution
4. Multiplication of the data of step 3 with the 'prevention costs at the norm', being the marginal costs per kilogram of bringing back the pollution to a level "in line with earth's carrying capacity".

The following 'prevention costs at the norm' are proposed for The Netherlands and Europe:
- prevention of acidification: 6.40 Euro/kg   (SO_x equivalent)
- prevention of eutrophication: 3.05 Euro/kg   (phosphate equivalent)
- prevention of heavy metals: 680 Euro/kg   (calculation based on Zn)
- prevention of carciogenics: 12.3 Euro/kg   (PAH equivalent)
- prevention of summer smog: 50.0 Euro/kg   (calculation based on VOC eq.)
- prevention of winter smog: 12.3 Euro/kg   (calculation based on fine dust)
- prevention of global warming: 0.114 Euro/kg   (CO_2 equivalent).

These 'prevention costs at the norm' are based on the so called 'marginal prevention costs' of emissions. The way these marginal prevention costs are determined is depicted in Figure C. For each type of emission, the costs and the effects (in terms of less emissions) are accumulated for several prevention measures to be taken (a 'what if' calculation). At a certain point on the curve, the 'norm for sustainability' is reached. The marginal prevention costs are defined by the costs per kg reduction of the 'last' measure, depicted as line b. The 'norms for sustainability' are based on the 'negligible risk levels' for concentrations (in air and in water) and the corresponding 'fate analyses', being the link between concentration and emissions.
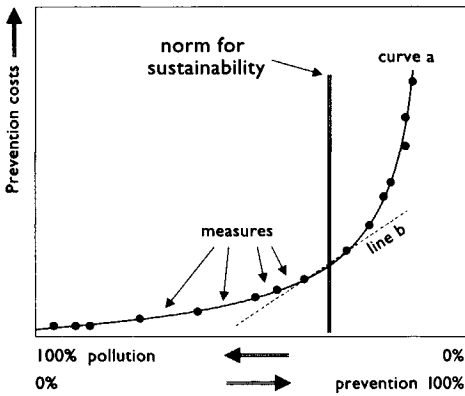
Fig. C: The way the marginal prevention costs are calculated from emission prevention measures for
        a certain region.

(See Section 2)

The End of Life stage

The End of Life systems are rather complex. For complex products, like buildings,
there are many different system opportunities to make the solution more sustainable
(from recycling to enhancement of the durability).
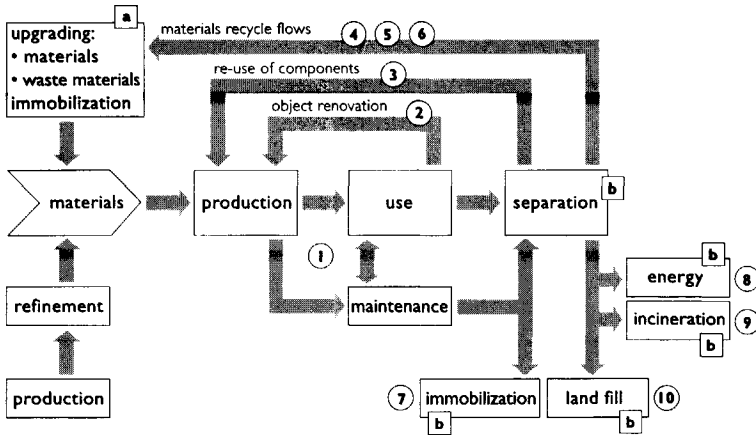
Fig. D: The flow of materials in the Life Cycle.

Figure D depicts the major types of End of Life treatment and types of recycling. It is
developed to describe and analyse the various kinds of complex modern life cycles of
consumer products, buildings, manufacturing plants, civil structures, etc.

The numbers in Figure 5 relate to the "Delft Order of Preferences", a list of the 10 major systems for End of Life used for structured and systemized analyses of (combinations of) design options:

1. Extending of the product life
2. Object renovation
3. Re-use of components
4. Re-use of materials
5. Useful application of waste materials (compost, granulated stone and concrete, slag, etc.)
6. Immobilization with useful appliances
7. Immobilization without useful appliances
8. Incineration with energy recovery
9. Incineration without energy recovery
10. Land fill.

It is important to realize that for big, modular objects (like buildings), there is not "one system for End of Life" but in reality there is always a combination of systems. Two basic rules for allocation in the EVR model are:
- Costs and eco-costs of all activities marked with 'b' are allocated to the End of Life stage of a product (transportation included).
- Costs and eco-costs of all activities in the block marked with 'a' are allocated to the material use of the new product (so are allocated to the beginning of the product chain).

In line with the aforementioned allocation strategy, the 'bonus' to use recycled materials is taken at the beginning of the product chain, where the new product is created. Material depletion is caused here when 'virgin' materials are applied, material depletion is suppressed when recycled materials are applied.

(See Section 4)

The EVR as an indicator for de-linking economy and ecology

Product designs for the future will need to combine a high value/costs ratio as well as a high eco-efficiency. The advantage of the EVR model is that it can reveal how the de-linking of economy and ecology can take place in practical situations.

For designers, the EV Wheel has been developed, showing the strength and weakness of a certain design on the value side as well as the eco-costs side. See Figure E. A sustainable design is characterized by high scores at the value side and low scores at the eco-costs side.
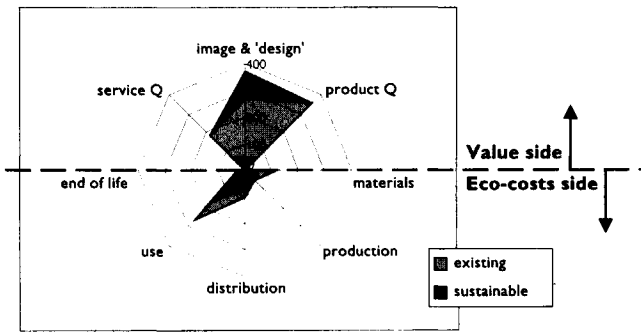
Fig. E: The Eco-costs & Value Wheel (EV Wheel), with value and eco-costs (Euro).

Another powerful instrument to analyse a product is an eco-costs value chart of the manufacturing, assembly and distribution chain. In the production chain, the value as well as the eco-costs gradually increase from the raw materials to the point of sales. This is depicted in the example of a 28" television in Figure F.
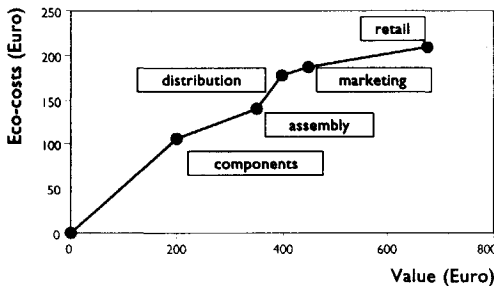
Fig. F: The value and the eco-costs cumulative along the production and distribution chain
(data for a 28" television).

The EVR is also a good indicator of the sustainability of consumers expenditures. The so called "rebound effect" is depicted in Figure G, showing that 'savings' are some-times not a good solution for sustainability. When eco-costs are reduced by 'savings', the economic value (costs for the consumer) is reduced as well, so the consumer will spend the money somewhere else. In the example of product 1 of Figure G, the net result is positive, since the money which is saved, is spent on another product with a lower EVR. In the example of product 2 of Figure G, however, the net result is nega-tive, since the saved money is spent on a product with a higher EVR. The conclusion is that "savings" are only positive for the environment when savings are achieved in areas with a high EVR (and spent in areas with a low EVR).

A typical example of the rebound effect is related to the efficiency increase of light bulbs: when consumers spend the saved energy on more light (e.g. in their gardens)

or on electricity for other domestic appliances, it does not help much in terms of sustainability.

In general, however, one may conclude that savings on energy can have a positive effect in terms of sustainability, since the EVR of energy is relatively high (1.2 – 1.8) in comparison with other expenditures. Savings on luxury goods (generally a low EVR because of the high labour content: 0.2 – 0.4), might be negative since the "rebound" might be in the area of more energy (in the form of travel).
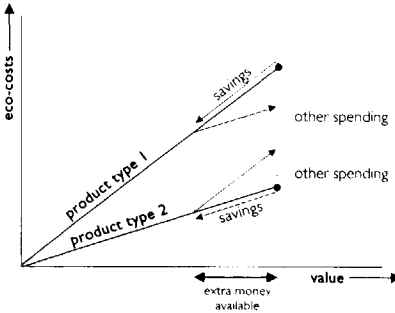
Fig. G: The "rebound effect" of consumer expenditures.

(See Section 5)

Case: the transport function

To illustrate the advantage of the EVR model in cases where service plays an impor-tant role, a transport chain has been analysed: vegetables from the Dutch greenhouse to the retail shops in Frankfurt. The chain has been analysed for two transport pack-aging systems: returnable crates and 'one way' solid board boxes. See Figure H.
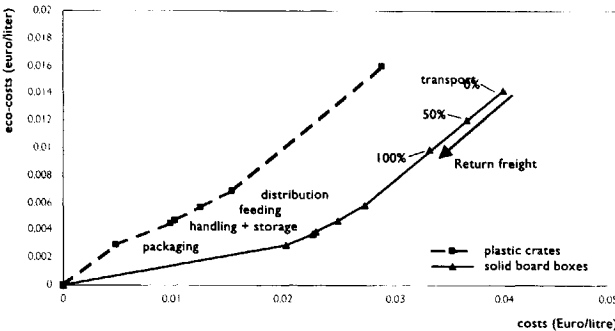
Fig. H:. Costs and eco-costs per litre net transport volume for the total chain (total distance 500 km) as function of the percentage return freight.

For the design of transport systems an integral LCA approach of the total transport chain (cycle) is required to minimize eco-costs. This is because of the high interaction of the system components: the packaging system, the transport system and the storage system. Efficient use of volume (of the truck as well as of the transport packaging) plays a key role as well as the re-use of packaging materials.

The eco-costs for the solid board box system appeared to be lower for all cases (also for shorter distances), especially when the truck can be used for other freight on the return trip. The EVR (and therefore the eco-efficiency) of the solid board box system is in all cases considerably better as well. So there is no reason from the environmental perspective to prefer plastic re-usable crates, which is an embarrassing conclusion in the light of the discussions in The Netherlands that started in the early nineties: 'durable' does not go hand in hand with 'sustainable' in this case, because the use of energy appears to be rather predominant in those transport systems.

(See Section 6)

The eco-costs of land conversion

Although it is argued that land-use cannot be integrated in the LCA of industrial mass products, a characterization system has been developed for conversion of land. This system might be used in:
- LCAs of one-off products like buildings, roads etc.
- rural and urban planning, to determine the best option and to assess possibilities of compensation (e.g. in the Dutch MER system).

The calculation system for the eco-costs of land conversion is summarized in Figure 1. In the calculation scheme of Figure 1 it is shown that two category indicators can be used for the endpoint category 'habitat for plants': either SRI (for species richness) or ERI (for rarity of vascular plants). For ERI a threshold value has been built in: when ERI is more that 1 conversion should be forbidden.

For the endpoint category 'H_2O cycle', a category indicator has been developed for the specific case of the Dutch polders. For other cases a category indicator is still to be developed (for the conversion from green areas to built-up areas). These eco-costs tend to be low, however, in comparison to the eco-costs of scenic beauty.

In calculations of eco-costs, two aspects seem to be dominating:
a. the botanical valuation of nature, in situations where a green area is converted to a green area of an other type
b. the scenic beauty, in situations where green land in urban areas is converted to built-up land.

The calculations on eco-costs can be used in order to determine measures for compensation in spatial planning. Such a compensation has to be done within each endpoint category separately (e.g. negative effects on the H_2O cycle must be compensat-
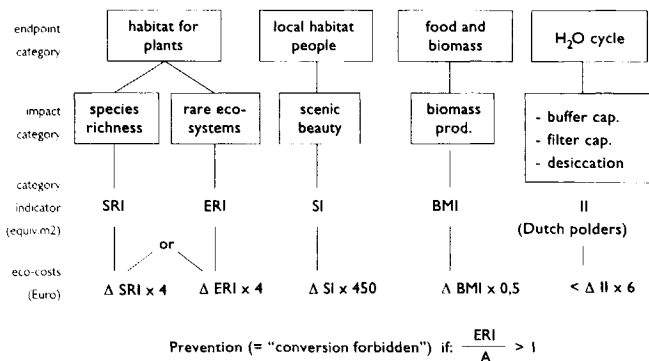
Fig. I: Characterization system for land conversion, and the corresponding eco-costs

ed by positive measures in the field of the H_2O cycle, and not in the field of botanical value or scenic beauty).

(See Section 7)

Aspects of communicating the eco-costs and the EVR

It has been tested whether or not the EVR model leads to a good understanding of the eco-efficiency of a product-service combination. In an experiment, 3 separate groups of 8-11 people were asked to rank four alternative solutions of a product-service system (the after sales service and the maintenance service of an induction plate cooker) in terms of sustainability. The 3 respective groups were:
-   customers (among whom representatives of consumer organizations)
-   business representatives from the manufacturing company of the induction plate cookers
-   governmental representatives (employees of the Dutch ministries of environmental affairs and economic affairs, and of the Dutch provinces as well as consultants involved in governmental policies), all experts in the field of sustainability.

The question was to rank the proposed alternatives in terms of "best sustainability" as well as in terms of "best choice in general", and to give arguments for the chosen answers. Furthermore it was asked what information was missing to make "the right" decision on the ranking (as it was perceived by the participants). At the end it was asked whether the eco-costs and the EVR were perceived as good criteria on which to base decisions.

From the experiments it can be concluded that:
-   The concept of Eco-costs was accepted by the majority of the non-experts, better than LCA output on which to base their ranking
-   The concept of the EVR was understood by the majority of the non-experts, but

the consequences of it in terms of life style were not easily accepted (especially the consumers group rejected the idea to judge on *their* life style by an eco-efficiency parameter)
- The environmental experts in the governmental group did not directly accept the concept of eco-costs model (they wanted in depth information first); they tend to stick to their existing knowledge of LCA data, which is in line with Rogers' theory of diffusion of innovation.

The experiment indicates further that:
- the aspect of sustainability plays hardly any role in the decision when a consumer has a strong preference (based on other aspects, like the cost/benefit ratio) for a certain product type
- however the aspect of sustainability can play a quite important role in the decision when there is no preference on other grounds.
This way of selection of products and services is depicted in Figure J

1st Filter: 2nd Filter:
quality and price?   environmentally OK?
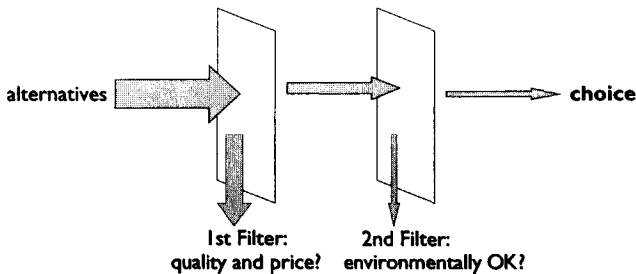
· Fig. J: The Double Filter Model : environmental data serve only as a second order filter in the decision of consumers.

(See Section 8)

The road towards sustainability

The combined approach of eco-costs and value reveals new opportunities to reach "the factor 4" in eco-efficiency (or even more). The required transformation , however, is far from easy. In order to describe the mechanism of the required transition, the 'three stakeholders model' has been introduced. See Figure K. This model provides the main interactions between business, government and consumers/citizens with regard to the issue of sustainability:
- citizens ask the government to care for their long term interest and to create sustainability
- the government defines restrictive rules and has to create an even playing field for the industry
- the industry satisfies short term consumers needs in terms of maximum value for money.
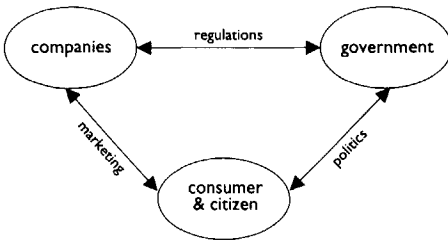
Fig. K: The 'three stakeholders model' and their main interactions.

With regard to the introduction of green products, the EVR model reveals two important issues:
- in the product portfolio management strategy companies have to enhance the EVR of products with a high value/costs ratio (rather than try to enhance their cost / value ratio of products with a low level of eco-costs, as many environmentalists propose). See Figure L.
- marketing strategies need to be differentiated:
  - for commodity products (products where it is hard to differentiate on price/value), make the low eco-costs of a product a competitive edge, but keep the price/value at the same level
  - make the eco-costs part of the image for special products and high quality products, but do not stress the sustainability issues too much, since consumers go for the best price/value
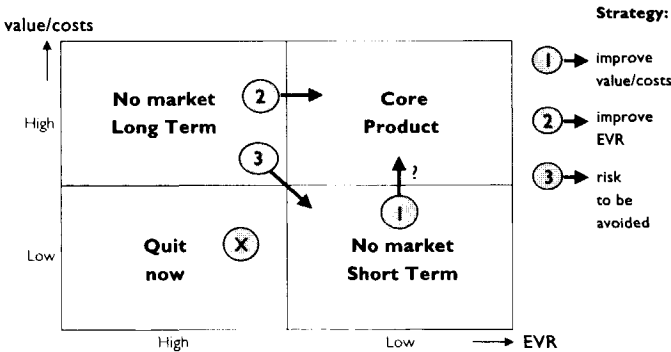
Fig. L: Product portfolio matrix for product strategy of companies.

It is shown why it is so difficult for governments to force the industry in the direction of sustainability, and keep an even competitive playing field at the same time. Gradually increasing tax on pollution would work in a closed economy, but has the adverse effect of 'exporting environmental pollution' in an open, global, trade. Tradable Emission Rights systems for the industry, in which the government take part, seem to be the most promising solution on national level.

On global level a Tradable Emission Rights system between governments might become the right tool to freeze the CO_2 emissions to its current level. Drastic and fast reduction of the emissions, however, cannot be expected from such a system. The goal can only be reached step by step.

Systems of subsidies (or tax relief) on consumer products are suitable to facilitate the market introductions of innovative products, but only in market niches, and only for products with a high EVR. General subsidies (or tax relief) for other than these products have to be avoided.

(See Chapter 9)

Joost G. Vogtländer
Delft, 2001

1. Introduction.

Abstract

This Section deals with the research questions, the research methodologies, the structure of the research activities and the structure of this report.

1.1 The need for a structured approach.

The need for a new model is – apart from my personal motivation as described in the Preface – caused by three phenomena:
1. The fragmented and partial approach of resolving environmental problems.
2. The lack of understanding of the link between a prosperous economy and a sustainable ecology in relation to strategy development of companies and governments.
3. The lack of clear communication between environmental experts on the one side and people who take strategic decisions on the other side.

With regard to point 1, we know that there are many initiatives to support the development of a sustainable[1] society, all based on a general feeling of what sustainability is supposed to be:
I. In business:
 a. reduction of emissions of toxic materials
 b. reduction of waste generated by production processes
 c. improvement of awareness (and image) by 'green labelling' (e.g. for packaging)
 d. improvement of durability (e.g. of light bulbs)
 e. development of new materials (e.g. for batteries)
 f. development of recycling systems (e.g. packaging and computers)
 g. innovation in the design of products (Design for Sustainability).

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[1] See Annex 1a for the definition of sustainability. This definition comprises three aspects: 1. Environmental, 2. Economic, 3. Social. In this thesis, only the environmental and economic aspects are dealt with, and the way these two aspects are interrelated (the so called eco-efficiency).

II. By the government:
   a. rules and regulations (e.g. nuisances act)
   b. subsidies and taxes
   c. 'convenants' (agreements) with industrial sectors.
III. By the citizens:
   a. action and pressure groups
   b. product bans (boycotting).

But what is the coherence between all these actions and activities? Which strategic choice is the best one at which moment in time? How do we distinguish between essentials and side-issues? How can we avoid unintentional negative side-effects? How can we make sure that measures are in line with each other instead of counteractive? Although the aforementioned measures have a positive effect on the 'de-linking' of the economy and the ecology in the OECD countries (Kageson, 1998), and in The Netherlands (Huele et al., 1999), still little is known about the integral coherence of cause-effect relations. The fact that this 'de-linking' has urgently to be enhanced is generally accepted, however, how to achieve it in a structured way is still to be defined, see Annex 1a. Consumers and business people get blurred by the ever changing sustainability issues (action groups try to draw attention and raise awareness by creating continually new hypes), creating a confused feeling of indifference. Is there a possibility of a more integral approach, supported by a better understanding of sustainability, than merely "faith in the good cause"?

With regard to point 2 we may conclude that the main objective of each party involved is not sustainability as such, but rather economic prosperity in general:
- companies will aim at maximization of profit
- governments will aim at maximization of prosperity (for all inhabitants)
- consumers/citizens will aim at maximum value for their spent money.
In the short term, sustainability is not very high on the agenda. On the long term, all parties involved seem to be aware of the fact that economic prosperity cannot last without ecological sustainability, so there is a need for eco-efficiency. But what is eco-efficiency in practice?
The crucial question is how to bring the economic interest in line with the ecological interest. Not only in the philosophical sense, but above all in terms of choices to be made in policy and strategy, and in terms of actions to be taken. In order to make progress, we have to know which aspects and which mechanisms of the two different interests are in line with each other and which aspects and mechanisms are counteracting.

In order to create the most efficient and effective approaches to tackle the complex reality of introducing sustainability (e.g. in the situations as described in the Preface), a clear understanding is required of the issues and interrelations of the several sub-systems. This has induced:
- the development of a (LCA based) monetary indicator which enables the comparison of the several aspects of sustainability: the 'virtual eco-costs'
- the development of a model to describe the relationship between the sustainability aspects of product-service systems and the economic aspects of the same product-service systems: the 'Eco-costs / Value Ratio'(EVR).

With regard to point 3 we may conclude that the standardization of the LCA methodology has not yet resulted in a better situation with regard to the communication of the outcome of an LCA (Bras, 1999). This was the reason to check whether the results of the EVR model (based on LCAs as well!) were easy to communicate to consumers/citizens, business managers and governmental representatives.

1.2 Current definitions of eco-efficiency

The connotation of 'sustainability' is "keeping up for a long time". In the Dutch language there is even no difference between the translation of 'sustainability' and 'durability': both words are the same. The connotation of 'sustainable' in The Netherlands is therefore "a product with a long lifetime" (the opposite of a product of our 'throw away society').
This connotation of sustainability supports the idea that the essence of sustainability is elongation of the lifetime of the products in our society, which will reduce the rate of depletion of materials.

The usual definitions of 'eco-efficiency' are related to this idea of 'a long lifetime', which is in line with the fact that often the 'functional unit' of the LCA is related to the lifetime of the product. Eco-efficiency is defined then as (Van Nes et. al, 1998):

$$[1.1] \ eco\text{-}efficiency = \frac{(time \ of \ usage \ during \ the \ Life \ Cycle)}{(Life \ Cycle \ Impact)}$$

This way of defining eco-efficiency has been used by designers of Philips and Sony Europe to optimize their electronic products (TVs, videos etc.), where the LCI is defined by a single indicator for emissions (e.g. the eco-indicator '95 or '99). The use of such a definition of eco-efficiency is satisfactory for comparison of design alternatives of *the same product.* However, comparison of different product-service systems is not possible by this definition, since:
- The 'time of usage' is only one of the elements of the value of a product-service system (as it will be explained in Chapter 5.2 of this thesis)
- The 'time of usage' differs for different market niches (Van Nes, 1998b) and is not always equivalent (linear) to a low 'materials resource intensity', as will be shown in the examples hereafter.

Example 1: a TV.
For TVs the eco-efficiency is according to equation [1.1]: $\frac{(hours \ watching)}{(LCI)}$

The energy consumption in the life cycle is the most important component of the LCA. The energy consumption during the 'use phase' of the life cycle is about 2/3 of the total energy consumption. Hence, a quantum leap forward in eco-efficiency can be achieved only when the energy consumption during the use phase is reduced (there is an analogy with light bulbs).

But how about the fact that a TV is often thrown away because its technology or its design is out-dated (as is the case with computers as well)? Then the 'hours watching' is determined by other factors than the technical lifetime. Is it wise then to shorten the technical lifetime, or to design for the possibilities of upgrading of components? Anyway: the 'hours watching' is not easy to predict and will be different for different market segments. The issue of sustainability appears more complex than elongation of the technical lifetime.

Example 2: a car
For cars elongation of the lifetime seems still an interesting option. The problem though is that there are two market segments, requiring two fundamentally different sets of functional specifications:
-   the company cars, requiring a maximum durability in terms of distance (km)
-   the private owners, requiring often a maximum durability in time (years).
In terms of the aforementioned definition of eco-efficiency this results in two values of the eco-efficiency. The use of cars in terms of eco-efficiency is optimized by our western free market economy: most of the bigger cars are used as a company car in the first half of the lifetime (driving many km) and then sold to private owners for the second half (serving many years).

Example 3: transport packaging
The eco-efficiency of transport packaging (according to the aforementioned defini-tion) depends on the type of usage:
-   for short distance transport, reusable crates are the best solution in terms of eco-efficiency, since the negative effects of the return of the empty crates are of minor importance in the LCA
-   for medium distance transport, the negative effects of returning the empty crates become considerable; hence one-way packaging (when recycled) becomes the best option
-   for long distance transport the volume of the packaging material itself becomes a governing factor, hence the design has to have thin, but strong, walls.
Since a transport packaging system is basically a service system (enabling transport of other goods), the design of such a system has to integrate all elements and all aspects of the transport chain (packaging, energy of transport, damage of goods, etc.). Eco-efficiency is therefore related to a complex variety of aspects.

Example 4: an office building
The eco-efficiency of an office building is hard to determine because of the unknown 'end of life' scenario (often after more than twenty years):
-   sometimes an office building is completely demolished after its lifetime
-   more often the concrete skeleton is used to create a new, modern, building
-   sometimes (in historic city centres) the outer skin is renovated and the inner con-struction is completely renewed
-   in most cases it is refurbished more than once in its lifetime.
So what is the 'lifetime' of an office building? Who knows what will be the end of life scenario in its future?

This example shows a flaw in the existing methodology of the LCA as well: how should end of life scenarios be dealt with in the LCA?

Example 5: a dinner
'Having a dinner in a restaurant' might be an extreme example of a service, but it is a quite relevant example in terms of sustainability. 'Dining out' is a fast growing service market in our society, contributing to our prosperity. It has relevant aspects in terms of sustainability as well, which is illustrated by the following example.
Suppose a young Dutchman has 200 Euro to dine out with his girl friend. He has two possibilities:
a. he will visit a culinary restaurant ('French haute cuisine') in Amsterdam: they will have there a superb dinner
b. he will book a weekend in Paris (take the Thalys, eat in McDonalds): they have a superb weekend as well.
It is obvious that alternative a is much better for the environment than alternative b. But the classic definition of eco-efficiency cannot be applied, since it is hard to define a 'functional unit'.
Note: the crucial question is here on what the man will spend his money (even when he stays at home he will spend the 200 Euros somewhere else). So the concept of eco-efficiency should not be limited to the producers side, but should also be applied to the consumers side. The life style of consumers heavily influences the sustainability of our society. Not in terms of *whether* they spend money or not (consumers will spend their money anyway), but in terms of *how* they spend their money.

Conclusions of the aforementioned examples:
A. The classical definition of eco-efficiency (according to equation [1.1]), can only be used for comparisons of similar products; it is not suitable for general analyses, since the contents of the numerator changes for each different subject.
B. Eco-efficiency is related to the specific use (the life style) of the consumer as well.
C. A new model for eco-efficiency should enable an integral approach to the complex choices with regard to the ecological and economical aspects of product-service systems.

Note that these conclusions are valid for the existing methodology of LCA as well: the choice of the 'functional unit' has to be different for different subjects. Rather than throwing away the entire LCA methodology because of this flaw, it seems wiser to introduce a 'functional unit' which can be applied in a broad area of cases.
Environmental economists have 'value' or 'value added' as a natural 'functional unit'. They apply it to their 'input-output' tables on the national level, and they apply it to company accounting. In corporate environmental accounting a new definition of eco-efficiency has been proposed (Schaltegger et al., 1997):

$$[1.2] \quad eco\text{-}efficiency = \frac{(value\ added)}{(environmental\ impact\ added)}$$

Although it was decided to deviate from this definition in the EVR model, the basic idea behind this definition was adapted: compare the 'value' of the 'functional unit', with the 'environmental impact' and try to give the 'environmental impact' the same dimension as value (in order to make the equation dimensionless). This will be further explained in Chapter 3.2.

1.3 The aim of the new model.

For the development of the EVR model, there were 4 points of departure:
1. There is a need for a *quantitative* approach with '*a single indicator*' for environmental burden, to be able to analyse, design, communicate and implement strategies on sustainability.
2. It is important that strategies on sustainability will lead us in the right *direction*, it is less important to know everything about the future in great detail and great accuracy.
3. The transition towards a sustainable society will be easier and therefore faster when economy is brought *in line with ecology*.
4. It is important to keep models as simple as possible to be able to explain the results to large groups of citizens/consumers, business managers and politicians, in order to mobilise enough people to gain the required momentum for change.

The aim of the new EVR model is:
- enabling of the comparison of complex product-service systems,
- improving the understanding of sustainability in general,
- supporting the decisions of designers of products and services during all stages of the design processes,
- providing business managers with investment criteria to cope with the issue of sustainability,
- providing citizens/consumers with criteria to facilitate the right judgements in purchasing of goods, products and services,
- improving the understanding of the role of sustainability in Long Term company strategies,
- improving the understanding of how to bring sustainability into line with economy in the future development of the Western countries as well as the developing countries; improving the understanding of governmental policies on regulations, legislation, subsidy and taxation.

1.4 The R&D methodology

The model of the Eco-costs / Value Ratio has been developed in an iterative way. The model was designed first on the basis of analyses of the 'design requirements' for the new model and analyses of existing models, then the new model was tested on several cases, and finally methods were defined to apply the model in design and engineering. The research questions (tasks) of this thesis were:

1. develop a single indicator for toxic emissions, (if possible to be monetarized, and later to be expanded to use of energy, and materials depletion)
2. develop an indicator for 'eco-efficiency'
3. enhance the allocation methods in the current LCA methodology to cope with the allocation problems in calculations of services
4. make a new model for the End of Life stage of complex products (like buildings)
5. define consequences of the new model for 'eco-efficiency' for design and business strategies, check with cases
6. apply the EVR model on one complex service system, being a transport case (related to the strategic dilemma of the manufacturer of transport packaging as mentioned in the preface)
7. develop a single indicator for land-use
8. establish the hurdles in communication of environmental issues and relate them to the new model
9. define the consequences for companies and governments.

The research questions 4 and 7 were added at a later stage of the research to cope with the complex sustainability issues with regard to the building industry and to cope with spatial planning issues.

The research activities are depicted in figure 1.1.
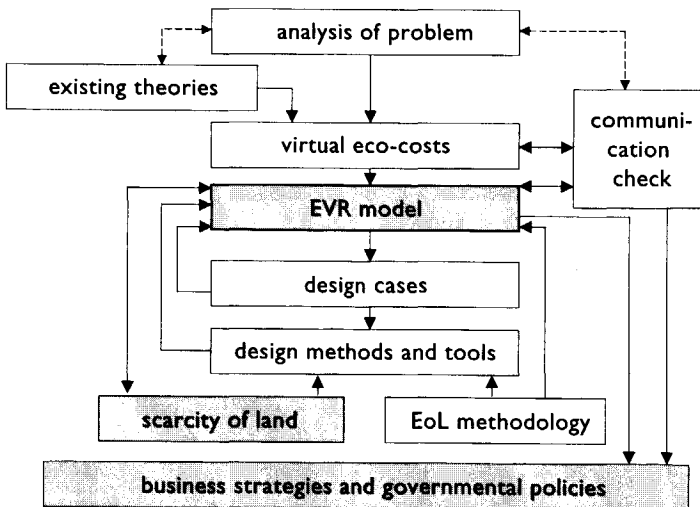
Fig. 1.1: The methodology of the development of the EVR model.

The sequential steps of the research project can be summarized as follows:
- First an analysis was made of models for LCA based 'single indicators' (30 models have been looked at).
- Then the 'virtual pollution prevention costs '99' and the 'virtual eco-costs '99' were developed by Morphology (for a short description of the methodology of Morphology, see Annex 1b).
  Note that the Swedish EPS model was rejected as a viable solution in an early stage, basically because the weighing system in EPS is 'damage based' (the method-ological flaws of damage based weighing systems will be explained in Chapter 2.3).
- During the same period the EVR model was designed, and the two aspects were integrated in this EVR model (a model for economic allocation in LCAs as well as an indicator for sustainability).
- Then the EVR model was checked against cases from literature (TVs, cars): was the model applicable to product-service systems, and did the model really lead to a better understanding of sustainability issues?
- It was checked quite early on in the design stage of the model as to whether or not the model could be easily communicated to citizens/consumers, business man-agers, and governmental representatives: was it easy enough to reach a level of suf-ficient understanding on the sustainability issues, where the target groups were the non-specialists?
- The case which was studied in depth was a transport chain (a hub-and-spokes sys-tem), being an example of a complex service function.
- As a result of the case (and as a result of the fact that other people started to apply the model as well) a methodology was developed on how to apply the model in the design stage of products and service systems, resulting in a special EVR database in the Ecoscan computer program and a manual on how to apply it.
- It was felt that the model could be applied to the civil construction industry as well: in two design cases it was tested as to whether the EVR model had added value to the many other models which exist in Dutch building industry.
- A comprehensive EoL methodology was added to the model, to cope with the complexity of renovation of buildings and recycling of building elements, and other complex products like cars.
- Since scarcity of land is an important issue in Dutch rural and urban planning, a single indicator was developed (applying Morphology, see Annex 1b) defining how to cope with this issue in the EVR model.
- Finally, the strategic consequences for companies and governments were analysed.

Another aspect of the research methodology was that the content of the thesis was determined in the early stage of the research activities, so that each Section of this thesis was written immediately after finalising the underlying activities. This approach made it feasible to incorporate comments of expert readers on these Sections (basi-cally this is the methodology of Synectics, see Annex 1b). It made expert interviews highly effective, and the iterative design process efficient.

1.5 The structure of this dissertation

This thesis is basically a compilation of a series of articles for publication. Consequently, the reader is not forced to read the ten Sections in this thesis sequentially, since each Section stands on its own. After reading the summary, a reader can pick out the Sections of his or her interest (and find out later the other detailed information in the other Sections).

Of the following Sections, nearly verbatim versions were published in separate articles:

Section 2, dealing with research question 1: the basic methodology to develop a single indicator for toxic emissions (Vogtländer et al., 2000).

Section 3, dealing with research question 2: the basic philosophy of an indicator for 'eco-efficiency', and research question 3: the allocation model for services (Vogtländer et al., 2001a).

Section 4, dealing with research question 4: the problems of modelling the End of Life stage (Vogtländer et al., 2001b).

Section 5, with research question 5: the consequences for engineering, with some cases (Vogtländer et al., 2001c).

Section 8, dealing with research question 8: the problem of communication of environmental issues (Vogtländer et al., 2001e).

Of the following Sections, short versions or main issues are to be published in separate articles:

Section 7, dealing with research question 7: the single indicator for land-use, publishing the part on botanical value (Vogtländer et al., 2001f).

Section 6, dealing with research question 6: the complex design case of the transport packaging function (Vogtländer et al., 2001d). This article will be summarized and translated into Dutch and submitted to a Dutch journal on logistics.

Section 9, dealing with research question 9: the consequences for companies and governments. Part of this section will be summarized, translated into Dutch and submitted to the Dutch journal ESB.

2. The "virtual pollution prevention costs '99",

a single LCA-based indicator for emissions

A new calculation model for interpreting the results of an LCA

Abstract

This Section deals with research task 1: develop a single indicator for toxic emissions.

In literature many models (qualitatively as well as quantitatively) can be found to cope with the problem of communicating results of LCA analyses with decision takers. Most models translate data on emissions in a single indicator, using a classification and characterization step. More than 30 of these models have been looked at, of which 14 have been studied in detail. From these analyses it was concluded that there is still a need for further development.

A new model for a single indicator has been designed on the basis of the following main criteria:
i. The model has to be easy explainable to non-specialists (i.e. the model has to relate to "normal life")
ii. The model has to be "transparent" for specialists:
    -   since the choice of the region influences all these kinds of calculations, specialists have to be able to adapt the data for the calculation to cope with the choice of a specific region (the data in this publication is for the Dutch and West European region).
    -   since the character of these calculations is that some arbitrary decisions cannot be avoided, the model has to have a structure that enables an easy assessment of the effect of these decisions, so that the experts can adapt the model to their own judgements.

Based on the analyses of the aforementioned existing models, it was concluded that a model based on the marginal prevention costs seems to give the best fit with the two criteria mentioned above.
These marginal prevention costs are assessed for seven emission effect classes on the basis of prevention measures which are based on readily available technologies. The costs of the measures are based on current West European price levels.

Essential to the model is that it has to be judged whether the set of measures is sufficient to reach a sustainable level of emissions. Given a certain region one can calculate the effect of the set of measures (provided that enough data on that region is available) for the current situation. These calculations, based on West European current price levels, have been made for The Netherlands as a region for the following classes of emissions:
- *acidification, eutrophication, summer smog, winter smog and heavy metals, based on previous work of IVM, Amsterdam*
- *global warming by CO_2 emissions based on previous work of ECN, Petten.*

Furthermore, it has been checked as to how the assumptions are related to the current emission targets of the Dutch government, and it is discussed how this data may relate to other regions in the world.

The following data set is proposed to be applied as marginal prevention costs:
- *6.40 Euro/kg SO_x equivalent for acidification*
- *3.05 Euro/kg PO_4 equivalent for eutrophication*
- *50.0 Euro/kg VOC equivalent for summer smog*
- *12.3 Euro/kg fine dust for winter smog*
- *680 Euro/kg Zn equivalent for heavy metals*
- *12.3 Euro/kg PAH equivalent for carciogenics*
- *114 Euro/1000 kg CO_2 equivalent for global warming.*

The "virtual pollution prevention costs '99" is proposed as a single indicator for emissions, being the sum of the marginal prevention costs of all aforementioned classes of pollution.

2.1 Introduction: the need for a single indicator

LCAs are often made to compare alternative solutions (for products, services, functions, etc.). But how to compare the results of two different LCAs? Only environmental experts are able to interpret the results, but their complex decisions are not easy to communicate to managers, designers, politicians and governments. One of the important issues here is the comparison of the several types ('classes') of emissions. Given the fact that the Life Cycle Analyses as a tool for the assessment of products and services has been nearly fully developed (only some details in de ISO definitions are still under discussion), the question now arises as to what to do with the results. There are two major issues in this area:
1. how to communicate the results of an LCA to people other than the environmental specialists
2. how to compare two (or more) alternatives for a product, service or function (i.e. how to compare two or more Life Cycle Inventories).

These issues get gradually more important when we, in our society, want to *do* something in the field of sustainability. Then the results of LCAs have to be communicated to the 3 stakeholders: governments, companies and consumers/citizens, in order to make clear to them which decisions are in the right direction in terms of sustainability. In the case of emissions, these issues are of extra importance, since the impact of

emissions will not show up directly, but only in the Long Term (when it is too late to do something about it). To enable these stakeholders to make the right decisions that will support a sustainable society, one yardstick is required for emissions.

2.2 The problem of weighing several types of emissions

A generally accepted route towards a single indicator is an approach which is based on splitting the problem into two levels (ISO 14040):
a. Combining emissions with the same nature of effect: the so called 'classification' in groups; followed by weighing of the importance of an emission within each class: the so called 'characterization' within the group. For each group this leads to an "equivalent weight of the major pollutant in the class".
b. Finding a weighing principle to add up the different classes.

For most of the major pollutants, the classification and the characterization factors (i.e. the weighing factors within classes) can be assessed from the chemical, physical or biological effect they have:
- acidification: characterized by simple formulas from chemistry
- eutrophication: characterized by simple formulas from chemistry
- summer smog: characterized by relative simple chemical reactions which form ozone
- winter smog: characterized by the "just detectable effect at long term exposure", norms given by the World Health Organization in the Air Quality Guidelines for Europe
- heavy metals: characterized by the "just detectable effect at long term exposure", norms given by the World Health Organization in the Air Quality Guidelines for Europe and Water Quality Guidelines for Europe
- carciogenics: derived from the rate of development of cancer (number of patients in a population of 1 billion people), given in the Air Quality Guidelines
- global warming: rather complex calculations on the reflection of light and its thermal consequences (note that only the relative effects of the several gasses have to be known for the weighing; the impact in absolute terms is a problem which has not yet been resolved).

The characterization factors resulting from the above criteria, which are used in the model for pollution prevention costs '99, are given in Table 2.1.

Note that all these weighing principles are based on the concentration levels in air or in water. If the rate of decay (or absorption) was known for all these emissions, it would have been possible to determine the sustainable emission norms because these norms could have been calculated for the "steady state of a closed region" (i.e. the total sustainable emission in that region is set equal to the decay or absorption rate of that matter at the maximum allowable air or water concentration). Unfortunately, there is no consensus about decay and/or absorption rates (e.g. part of the debate on global warming concentrates on the absorption rate of the earth of CO_2).

This is also the reason that pesticides cannot be dealt with in the aforementioned classification-characterization system: they differ enormously in decay rates. Pesticides with ultra short decay rates (a few days) are basically harmless and pesticides with decay rates of many years should be banned.
The problem of how to find weighing factors for the different effect classes is dealt with in the next chapter.

2.3 Weighing principles for the different classes

Since the chemical, physical and biological characteristics of the several classes differ, other weighing criteria have to be applied.

In general, there are 3 ways to weigh several different types of *potential* damage:
1. weigh the *negative value* of the damage (the '*impact*')
2. weigh the required effort to *prevent* the damage
3. weigh the required effort to '*repair*' the damage.

It is generally accepted that the third option is in general not the desired option for sustainability problems, since 'repair' of emissions is either not possible or much more expensive than prevention. (Examples of 'repair' are the attempts to restore regional biodiversity in town and country planning)
So we can weigh the classes either according to type 1 (impact) or type 2 (prevention).

In general, it is possible to weigh both impact or prevention by:
a. "points"
b. "money".
The four resulting possibilities for weighing are depicted in Figure 2.1.
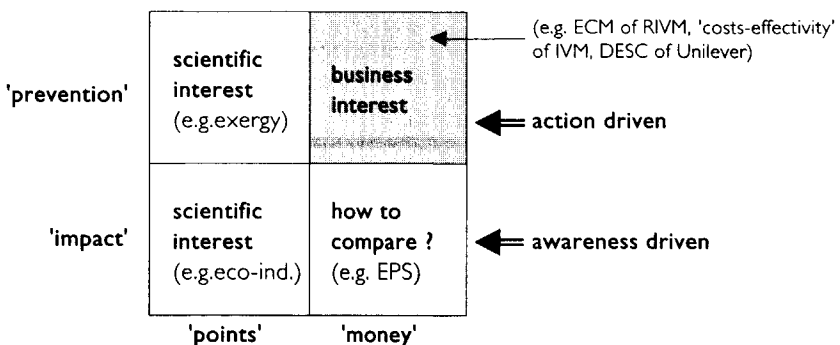
Fig. 2.1: Portfolio of models for a single indicator. (general literature on description of tools: Braunschweig et al., 1996; Lehni, 1998; Keffer et al., 1999; Tulenheimo et al., 1996; Graedel, 1998; Hoogendoorn, 1998; Nijland et al., 1998; Haas, 1997; Beetstra, 1998; Müller et al., 1997; Steen, 1996; websites of European projects on tools: Chainet, Deeds, ExterneE, WBCSD).

The vast majority of the models for a single indicator are based on the combination of 'impact' and 'points', perhaps a result of the fact that environmentalists often use LCAs to make other people aware of the gloomy problem (the potential damage or impact). The Swedish EPS model is based on 'willingness to pay' which is determined by assessing the negative value of the damage (impact), so this system is a combination of 'impact' and 'money'. In the exergy models, which are currently being developed, calculations are made on the prevention of emissions, so these calculations are a combination of 'prevention' and 'points'.

There are 2 macro-economic models which are not LCA based but which are basically a combination of 'prevention' and 'money': the Milieu Kosten Model (Environ-mental Costs Model) of RIVM, Bilthoven, and 'kosteneffectiviteit' (cost effectivity) of IVM, Amsterdam. The DESC model of Unilever is designed for micro-economic decisions (choices on products and processes) and also belongs to this category.

Models for weighing based on damage (impact) have two fundamental problems:
- weighing of the impact is a very subjective and arbitrary matter: how to compare a fatal illness with dying trees and/or extinguishing species?? (Finnveden, 1997)
- an assumption in damage based models is that the damage is proportional to the concentration and to the emissions, which is far from reality (see Annex 2a).
An additional argument to apply a prevention based model is of a practical nature: knowing that prevention is the required route towards a sustainable society, why weigh on the basis of impact? (shouldn't we prevent rather than accept the damage?)

Models for weighing based on prevention all suffer from the problem of setting the sustainable norms for emissions; basically there are three types of norms:
I. the absolute norms for maximum emissions at the sustainable level
II. the norms based on the economic optimum of prevention: the emission level where the costs of prevention equal the costs of damage (impact), see Figure 2.2
III. the current practice of prevention, being the 'revealed preference' (Huppes et al., 1997); note that this 'revealed preference' is not used here for target setting, but only for weighing of the relative importance of each of the classes.

The first method (I) suffers from the fact that, from a scientific point of view, it is not possible to predict these absolute norms (is the complex calculation method 100% correct? How can it cope with all future developments and risks?).

The second method (II) suffers basically from the same problem as the damage based methods: how to quantify the value of the damage caused by the emissions.
Note: In a qualitative form, however, this method in some specific cases plays a role in decision taking. An example is the ban on CFCs within the EC: it was obvious that prevention costs of using other gasses were much lower than the damage costs of the damage to the ozone layer. Another example is an attempt of the ExterneE project of the EC on energy (http://Externe.jrc.es/).
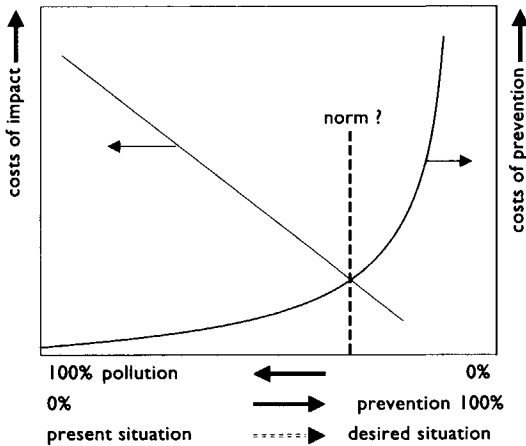
Fig. 2.2: The economic optimum as a norm for emission prevention?

The last method (III) is still under discussion at CML, Leiden. The key question here is whether this economic principle, valid for "free and transparent markets", can be applied for marginal costs of prevention of emissions as well.
One example exists where this method recently has been applied (implicit): a 'convenant' (agreement) between the Dutch government and the Dutch chemical industry, where "benchmarking of the world best practice" is used to agree on the measures to be taken to reduce the several emissions (Benchmarking is a modern management technique, used in many companies for medium term target setting). One might argue whether this technique generates targets which are stretched enough for sustainability purposes. Note, however, that targets set by benchmarking are 'moving targets', since a 'best practice' is getting better and better over the years, a process caused by competition).

It is evident that a perfect weighing principle does not exist. How to overcome this problem with a different approach is discussed in the next chapter.

2.4 The development of a new model

Since there is a need for a single indicator (as explained in the first chapter), and since there appeared to be no satisfactory existing one, it has been decided to develop a new model, based on the following main criteria:
- The model has to be easily explainable to non-experts (i.e. the model has to relate to 'normal life').
- The model has to be "transparent" for specialists:
  - since the choice of the region influences the calculations in the model, specialists have to be able to adapt the data to cope with the choice of a specific region (the first calculations of the model have been made for the Dutch

and/or West European region)
- since the character of these calculations is that some arbitrary decisions cannot be avoided, the model has to have a structure that enables an easy assessment of the effect of these decisions, so that the experts can adapt the model to their own judgements.

Based on the analyses of Chapter 2.3, it was concluded that a model based on the *marginal prevention costs* (see Annex 2a and 2c) seems to give the best fit with the two criteria mentioned above:
- the idea of prevention costs is easy to explain to non-experts (everybody is aware of the fact that measures to prevent emissions will cost extra money)
- the idea of marginal costs is easy to explain to non-experts (what does matter is the most expensive measure our society is prepared to take; strategies of introduction are easy to explain and discuss as well; consequences for business strategies are easy to explain and discuss)
- the methodology of marginal cost calculations is transparent as such for experts: experts can follow each step of the calculation and judge whether they agree on the data which is used, and they can assess the sensitivity for uncertainties of assumptions
- experts can make calculations for different regions.

The problem, of course, is how to deal with setting the sustainable norms for emissions (see Chapter 2.3 point I, II and III). The chosen strategy for this problem is: keep the model as simple as possible (so it remains transparent). This is achieved by the following methodology:

Step 1: estimate which set of measures (technical solutions, 'end of pipe' and/or process integrated) will meet the requirements for sustainability

Step 2: relate these arbitrary norms to calculations of absolute norms in literature and relate them to governmental (political) aims

Step 3: when the chosen norms of step 1 is not satisfactory in step 2, reset the norms in step 1 and repeat step 2; when the norm is OK, take the price of the most expensive measure.

In this way, the complex calculation systems on absolute norms (and the scientific discussions about them) are not integrated in the model, but are kept separate from the model on the marginal prevention costs. This separation of models is essential to keep the total system transparent (the complex situation with regard to greenhouse gasses is a good example, see the next chapter).

2.5 The norms in the model and how they relate to other norms and aims

Applying the methodology of the previous chapter, the following norms are proposed:
- 6.40 Euro/kg SO_x equivalent for acidification
- 3.05 Euro/kg PO_4 equivalent for eutrophication
- 50.0 Euro/kg VOC equivalent for summer smog
- 12.3 Euro/kg fine dust for winter smog

- 680 Euro/kg Zn equivalent for heavy metals
- 12.3 Euro/kg PAH equivalent for carciogenics
- 0.114 Euro/kg CO_2 equivalent for global warming.

The relationship with other norms for sustainability will be dealt with hereafter.

2.5.1 Global warming

The norm of 114 Euro/1000 kg CO_2 equivalent relates to the lists of prevention measures of Table 2.2 for reduction of 'greenhouse gasses' (end of pipe as well as process integrated measures). The list is a summary of measures that are technically feasible at current price levels used in the MARKAL and the MATTER models of ECN, Petten. The list applies to The Netherlands, but the list for Western Europe shows only minor differences (Gielen, 1999 and 1998). The importance of such a list is, that it shows which measures are included and which are excluded at a certain price level. It provides the reader with a feeling for the economic feasibility of certain types of measures:
- biomass for production of electricity: 20 – 50 Euro/1000 kg CO_2 equivalent
- CO_2 storage at production of electricity: 50 – 80 Euro/1000 kg CO_2 equivalent
- Renewables (windmills, solar heating systems): 80-114 Euro/1000kg CO_2 equivalent
At this price level, some measures are excluded, like biofuel for cars and Photo Electric Cells.

Calculations with the MARKAL and MATTER models for The Netherlands (Beeldman et al., 1998; Gielen, 1999) show that, starting a reduction programme in 1999, the Kyoto norm (- 6% in 2010 in relation to the level of 1990-1995) can just be reached at a norm of 80 Euro/1000 kg CO_2 equivalent.
Calculations with MATTER (Gielen, 1999) show that 114 Euro/1000 kg CO_2 equivalent can result in a reduction of 50% in 2030 (compared with the year 2000) for Western Europe as well as The Netherlands.

The aforementioned calculations show that the choice of 114 Euro/1000 kg CO_2 equivalent is somewhat arbitrary indeed:
- the Kyoto norm could have been met with 80 Euro (if immediate actions had been taken)
- renewables come only in at a level of 80 – 114 Euro
- is a reduction of 50% for Western Europe in 2030 enough? (a factor 4 can be reached at 500 Euro)

Depending on the vision, the norm of 114 Euro can be too high or too low. It might be concluded, however, that the norm is not "way out", to "begin with". The norm reflects current best practices, and can be used to manage the transition towards a sustainable society. When better calculations become available in due time, one might "tune" the norm.

2.5.2 Acidification

The norm of 6.40 Euro/kg SO_x equivalent for acidification relates to a list of 141 measures of RIVM, Bilthoven. This list of measures comprises all sectors of society (industry, agriculture, buildings and houses, transport, etc.). Economically feasible at the norm are 121 measures on this list, all based on commercially available technologies. Included are (among others):
- measures related up to the "EURO3-mid" norms for cars, trucks, busses and tractors
- a vast list of measures for low NO_x emissions in power plants
- 'low emission stables' and 'equilibrium nutrification' practices for fertilization of land.

IVM, Amsterdam, used the RIVM database to make a calculation for the Dutch situation based on the year 1992 (Dellink et al., 1997). See Figure 2.3. Applying the norm for the marginal prevention costs of 6.40 Euro/kg SO_x equivalent to the curve of Figure 2.3 results in an emission reduction 750 million kg SO_x equivalent per annum.
Calculations of IVM (Dellink et al., 1997) suggest an emission reduction of 635 million kg SO_x equivalent per annum (the calculation ranges from 485 to 775 million kg SO_x equivalent per annum).
To reach the emission norm of the Dutch government of 240 million kg SO_x equivalent per annum for 2010, the emission reduction has to be 720 million SO_x equivalent per annum.

Acidification in The Netherlands

reduction of emissions in million SO_x equivalent per annum
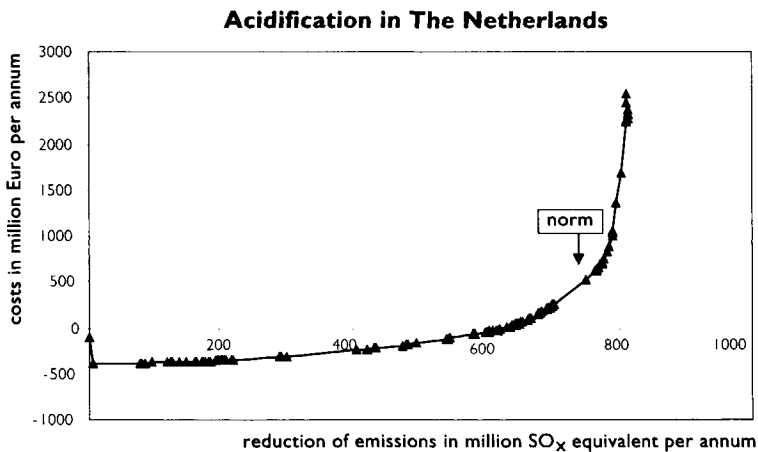
Fig. 2.3: The emision reduction curve for acidification in The Netherlands. Source IVM, Amsterdam (Dellink et al., 1997).

Note 1: The negative costs at the left end of the curve result from max. speed restrictions for cars (90 km/hr) and trucks (80 km/hr), resulting in reduced fuel consumption (calculated as savings).
Note 2: The lists of 141 measures does not comprise high tech solutions like the introduction of 'green cars', low emission chicken farms, manure conversion techniques, etc.

These measures tend to be slightly more expensive than the norm. Introduction of such techniques, however, will result in a lower slope of the tail-end of the curve.

2.5.3 Eutrophication

Calculations for eutrophication of land for The Netherlands are complex:
- the pollution within The Netherlands is of the same magnitude as the import and the export by the rivers
- the residence time in soil and water is several years, so the 'steady state' is complex to assess.

As a result of these factors, calculations and discussions about the subject are rather blurred.

For eutrophication of land a norm has been chosen of 3.05 Euro/kg PO_4 equivalent, being the price of sustainable manure processing.

Using the RIVM database for eutrophication, IVM calculated the situation for The Netherlands based on the year 1992. See Figure 2.4. The quantum leap from 15 to 340 10^6 kg PO_4 equivalent per annum is the result of sustainable manure processing. However, 340 10^6 kg PO_4 equivalent is approx. 50% of the estimated current emission level. The aim of the Dutch government is a reduction of a factor 4 for the year 2010. This seems to be feasible only when the total production of meat in Holland is reduced drastically, which is already a political discussion in Holland for many years, but which will now come to conclusion under pressure of EC regulations. The conclusion is that only a combination of measures (technical process improvements in combination with reduction of production) can lead to a sustainable situation.
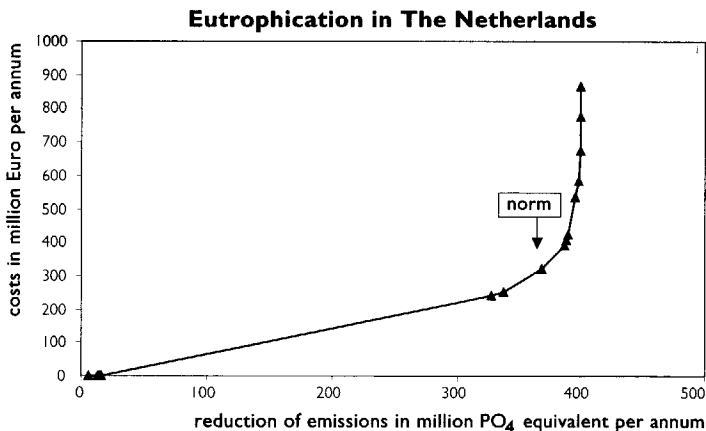
Fig. 2.4: The emission reduction curve for eutrophication of land in The Netherlands. Source IVM, Amsterdam, (Dellink et al., 1997).

2.5.4 Summer smog

The norm of 50.0 Euro/kg VOC equivalent for summer smog relates to a list of 31 measures of RIVM, Bilthoven. This list of measures comprises mainly of measures for cars, trucks and busses. The last measure which determines the marginal costs is the '2001 – stringent' emission classification for cars. (Note that this classification also includes a very low emission level for NOx.)

IVM, Amsterdam, used the RIVM database to make a calculation for the Dutch situation based on the year 1992. See Figure 2.5. Applying the norm for the marginal prevention costs 50.0 Euro/kg VOC equivalent to the curve of Figure 2.5, results in an emission reduction of approx. 180 million kg VOC equivalent per annum. Calculations of IVM suggest an emission reduction of 162 million kg VOC equivalent per annum (the calculation ranges from 112 to 212 million kg VOC equivalent per annum). Since measures against acidification and global warming effect summer smog as well, the Dutch government has no special aim and policy for this class of emissions.
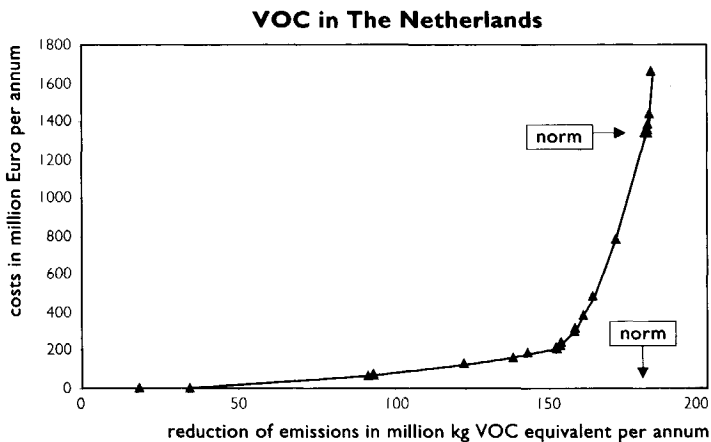
Fig. 2.5: The emission reduction curve for VOC (to reduce summer smog) in The Netherlands. Source IVM, Amsterdam, (Dellink et al., 1997).

2.5.5 Winter smog

The norm of 12.3 Euro/kg fine dust for winter smog relates to a list of 38 measures for reduction of fine dust of RIVM, Bilthoven. This list of measures is comprised mainly of measures for cars, trucks and busses.
The last measure which determines the marginal costs of 12.3 Euro/kg fine dust is the EURO 2 emission classification for diesel. (Note that this classification is also included in the measures for acidification).

IVM, Amsterdam, used this RIVM database to make a calculation for the Dutch situation based on the year 1992. See Figure 2.6. Applying the norm for the marginal prevention costs 12.3 Euro/kg fine dust to the curve of Figure 2.6, results in an emission reduction of approx. 35 million kg fine dust per annum. Calculations of IVM suggest an emission reduction of 30 million kg fine dust per annum (excluding industry). The calculation ranges from 25 to 35 million kg fine dust per annum. Note: These figures are excluding industry. Industry emissions are 40% of the total emissions and it is assumed that these emissions can be reduced by the same factor for even a lower price. Since measures against acidification and global warming effect fine dust as well, the Dutch government has no special aim and policy for this class of emissions.

Fine Dust in The Netherlands (excluding industry)
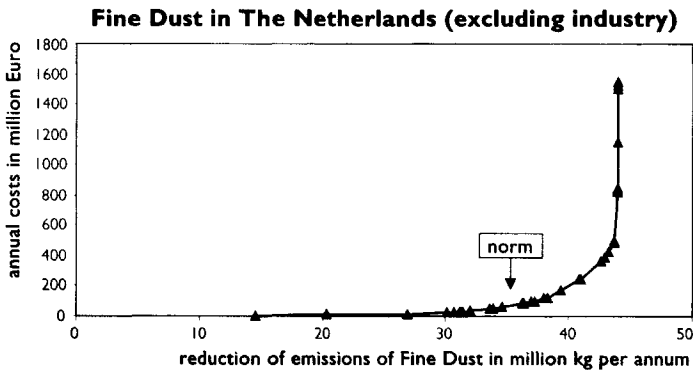
Fig. 2.6: The emission reduction curve for fine dust (to reduce winter smog) in The Netherlands. Source IVM, Amsterdam, (Dellink et al., 1997).

2.5.6 Heavy metals

The norm of 680 Euro/kg for heavy metals relates to a list of 14 measures for reduction of Zinc of RIVM, Bilthoven. This list of measures comprises mainly of measures for construction materials. Zinc has been selected to be the norm for heavy metals, since the emissions of Zinc count for about 60% (weight) of the total heavy-metals emissions. The last measure which determines the marginal costs of 680 Euro/kg Zinc is replacement of Zinc by coatings of construction materials (replacement of galvanized steel)

IVM, Amsterdam, used this RIVM database to make a calculation for the Dutch situation based on the year 1992. See Figure 2.7. Applying the norm for the marginal prevention costs 680 Euro/kg Zinc to the curve of Figure 2.7, results in an emission reduction to water of approx. 250,000 kg Zinc per annum. Calculations of IVM suggest an emission reduction of 250,000 kg Zinc per annum is required. This calculation is rather inaccurate and ranges from 107,000 to 407,000 kg Zinc per annum. The emission norms of heavy metals to be set by the Dutch government are currently still under discussion.
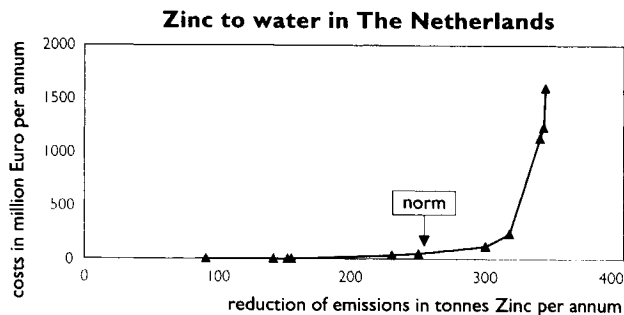
Fig. 2.7: The emission reduction curve for Zinc in The Netherlands. Source IVM, Amsterdam, (Dellink et al., 1997).

2.5.7 Carciogenics

For carciogenics there is no calculation of the prevention costs available.
As a norm, 12.3 Euro/kg PAH equivalent for carciogenics has been taken.
This is the same norm as for fine dust, since an important part of the cause for cancer is caused by fine dust (solid and/or liquid).

2.6 Example: the pollution prevention costs '99 of paper

As an example, a calculation of the pollution prevention costs '99 of the production of paper (wood based chlorine free bleached white printing paper) is given in Table 2.3. Data are from BUWAL (Oekobilanz von Packstoffen, 1990), Bern.

Note 1. The LCA of paper can vary considerably with the actual production chain (differences in production plants of pulp and of paper and differences in transport chains). Typical chains can deviate by a factor 2 or more from the average. Thus the LCA methodology as well as the method of pollution prevention costs '99 can only be used in benchmarking of production chains (comparing two or more cases). Data like the data in Table 2.3 can never be considered as "the absolute truth".
Note 2. As the calculations of the Simapro computer model are based on a similar set of characterization data, as mentioned in Chapter 2.2 and provided in Table 2.2, the Simapro output on the level of characterization data (the "equivalent weight") may be used as input for the last step of the calculation of the pollution prevention costs. However, one has to be careful here: a comparison of the two sets of data for classification and characterization show that Simapro counts some pollutants in two classes (e.g. CH_4, NO, NOx, ammonia) where these pollutants count only in one class in the pollution prevention costs model. The reason behind this is simple: these pollutants create damage in more than one impact class, but they have to be dealt with only once in terms of pollution prevention.

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2.7 Discussion[2]

2.7.1 "Virtual" costs.

It is important to mention that the curves of Figure 2.3 through 2.7 are relating to the present and not to the future. These curves describe the present state in virtual terms ("what if we already had taken the measures now"). Table 2.2 is also in current prices, the ECN calculations which are referred to in Chapter 2.5, however, make extrapolations in future years (applying economic growth scenarios).

All measures are readily available technologies at current price levels. It is important to realise that the tail ends of the curves will get flatter (bend to the right) in future because of two effects:
- 'technological learning curves' and 'economies of scale' when a technology gets widely applied in the market
- innovation of the technologies of measures and invention of new measures when big potential markets are expected to develop in the foreseeable future (because of the acceptance of a marginal cost level)

Case studies (Jantzen, 1995) on the history of prices for waste water treatment systems (for phosphor) and exhaust gas systems (desulfurization of exhausts of power plants, exhaust systems for cars) suggest that the 'technical learning effect' (price reduction) is 4% - 10% every year over the period of the first ten years in which these systems were introduced in full scale. The history of low NO_x burners show that innovation resulted in a price reduction of 15% - 30% every year over a period 6 to 10 years.

The conclusion is that one should avoid calculations which go too far into the future, since technologies and prices for measures have not yet been developed.

2.7.2 Why 'marginal prevention costs' instead of 'total prevention costs'?

An important aspect of the model is, that 'marginal prevention costs' have been chosen as norm, where these marginal prevention costs are defined as the maximum costs of a list of selected measures which are assumed to be sufficient to create a sustainable situation ("if we had taken these measures now, we would expectedly have a sustainable situation"). Figure 2.3 through 2.7 suggest that it is also possible to take the total prevention costs as a norm. However, in doing so, the character of the model will change: the total prevention costs are very sensitive for the choice of the region (with certain characteristics of density of population, regional industrial activity, etc.) at the moment in time (on the road to sustainability, these total costs will change constantly, whereas the marginal costs stay constant when the other parameters do not change). In the marginal costs model, the calculations on the total prevention effects (Figure 2.3 through 2.7) are *only for validation* of the norms: if similar calculations for the areas of Tokyo or Los Angeles show that the marginal costs norms have

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[2] *The publication of the theory of Section 2 (Vogtländer et al., 2000a), was accompanied by a 'call for comments'. The text of this call for comments is given in Annex 2b.*

to be more stringent, the 'virtual pollution costs' have to be adapted accordingly.

The idea of "the prevention costs of the most expensive measure of the list" relates to the idea of applying the 'best practice' (in terms of technical feasibility and economic optimum) for sustainability. The 'best practice' approach requires that the best practice will be applied in a total region, regardless of the fact that parts of that region could cope with less than the best practice (Example: In The Netherlands there is only a serious summer smog problem in the Rotterdam area, however, national emission norms are applied to the whole country to prevent "export" of environmental problems to relatively clean sub-regions). It is a political decision (the political will) to which area (the World, the Western World, the European Community or to one country) the norm will be applied. Only when norms are set for the whole World, problems like "export of environmental problems" and "levelling the commercial playing field" can be resolved definitely.

Note 1: The 'best practice' approach is already accepted within some big multinational companies. (Unilever has an environmental policy that *current* best practice technologies which are applied in e.g. Holland, also have to be implemented in production facilities in other parts of the world. Shell is trying to implement this way of thinking in terms of their norms and values as well)
Note 2: It is not allowed to add-up the total costs of prevention of Figure 2.3 through 2.7 to calculate the "grand total costs of prevention" for the region. The reason is that some measures do have an impact in more than one Figure, resulting in "counting double for one measure". Note that this effect does not influence the marginal prevention costs model.

2.7.3 How to deal with other prevention costs than of these 7 classes?

There has been a recent tendency to take many more classes into account. See Table 2.4 for some leading models. The model of the virtual eco-costs (where depletion of materials and fossil fuels is also taken into account), which will be introduced in Section 3 is an example of that.

We think, however, that the following 3 issues should be dealt with separately:
a. the "original" sustainability issues (pollution and depletion of the earth), which have a wider impact than just local and temporary effects
b. local health and safety issues (including the local damage of noise and smell, emission levels inside manufacturing facilities, etc.)
c. issues related to the conservation of nature (related to urban planning, planning of national parks, global master planning, etc.)

When these 3 issues are mixed up, the political discussions will get blurred. This is, for instance, debated in The Netherlands as to where to plan the future Amsterdam Schiphol Airport (to build an airport in the North See is a fair proposition from the point of view of health and safety, but not from the point of view of sustainability and/or conservation of nature).

The model which is presented in this section is a model for the first category only (point a.). It is not meant to deal with the other two categories (point b. and c.). The model of Section 7 goes beyond the use in LCAs only. This model is applicable in urban planning as well.

3. The Virtual Eco-costs '99 and

the Eco-costs / Value Ratio (EVR)

The "virtual eco-costs" as a single LCA-based indicator for sustainability and the "Eco-costs/Value Ratio" (the EVR) model for economic allocation
The EVR as an indicator for eco-efficiency

Abstract

This Section deals with research task 2: develop a single indicator for eco-efficiency.
This Section deals also with research task 3: enhance the allocation methods in the current LCA methodology to cope with the allocation problems in calculations of services.

In literature many models (qualitatively as well as quantitatively) can be found to cope with the problem of communicating results of LCA analyses with decision takers. In a previous Section, an LCA-based single indicator for emissions is proposed: the 'virtual pollution prevention costs '99'.

In this Section, a single LCA-based indicator for sustainability is proposed. It builds on the virtual pollution prevention costs '99 for emissions, and adds the other two main aspects of sustainability: materials depletion and energy consumption. This single indicator, the 'virtual eco-costs '99', is the sum of the marginal prevention costs of:
- *Materials depletion, applying 'materials depletion costs', to be reduced by recycling*
- *Energy consumption, applying 'eco-costs of energy' being the price of renewable energy*
- *Toxic emissions, applying the 'virtual pollution prevention costs '99'.*

The calculation model includes 'direct' as well as 'indirect' environmental impacts. The main groups of 'indirect' components in the life cycle of products and services are:
- *labour (the environmental impacts of office heating, lighting, computers, commuting, etc.)*
- *production assets (equipment, buildings, transport vehicles, etc.).*

To overcome allocation problems of the indirect components of complex product-service systems, a methodology of economic allocation has been developed, based on the so called Eco-costs / Value Ratio (EVR). This EVR calculation model appears to be a practical and powerful tool to assess the sustainability of a product, a service, or a product-service combination.

3.1 Introduction: the philosophy behind the model.

In march 1995, the World Council for Sustainable Development defined eco-efficiency as: *"the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity, throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity." (WBCSD, 1995)*

This business oriented definition links modern management practice (*"the delivery of competitively priced goods and services .... quality of life"*) to the need of a sustainable society (*"while progressively reducing ...... to ...... earth's carrying capacity"*). The first part of the sentence asks for a maximum value/costs ratio of the business chain, the second part of the sentence requires that this is achieved at a minimum level of ecological impact. But what does this rather philosophical definition mean to business managers, designers and engineers in terms of the practical decisions they take? There is a need to resolve simple questions like: what is the best product design in terms of ecological impact?, what is the best product portfolio in terms of sustainability?, what is the best sustainable strategy?

For that reason, the Delft University of Technology developed the eco-costs / value model as a practical tool for decision-making, based on the LCA methodology, and comprising the following features:

✓ one single indicator for the 3 major groups of environmental impacts (materials depletion, fossil energy consumption, toxic emissions)

✓ a relatively simple and well defined allocation model to cope with 'service' type functions (as service systems are characterized by many 'indirect' environmental impacts, shared by many other external systems).

The basic idea of the model is to link the 'value chain' (Porter, 1985) to the ecological 'product chain'. In the value chain, the added value (in terms of money) and the added costs are determined for each step of the product 'from cradle to grave'. Similarly, the ecological impacts of each step in the product chain are expressed in terms of money as well as the so called eco-costs. See Figure 3.1.
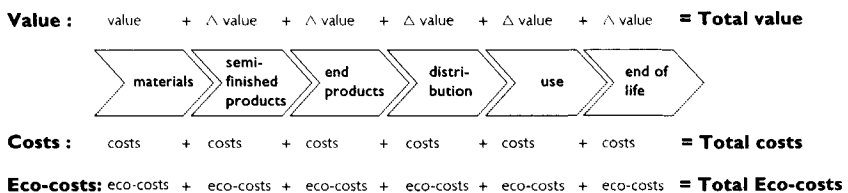
Fig. 3.1: The basic idea of combining the economic and ecological chain: "the EVR chain".

The eco-costs are 'virtual' costs: these costs are related to measures which have to be taken to make (and recycle) a product *"in line with the earth's estimated carrying capacity"*. These eco-costs are the sum of the 'marginal prevention costs' of each 'class' (type) of pollution[3], see chapter 3.3.1, and the costs of measures for prevention of material and energy depletion, see chapter 3.3.2 and 3.3.3.

Since our society is yet far from sustainable, the eco-costs are 'virtual': they have been estimated on a 'what if' basis. The costs of the required prevention measures are not yet fully integrated in the current costs of the product chain (the current Life Cycle Costs). The discussion whether or not it should be wise to integrate the marginal prevention costs in the product costs (by means of 'eco-tax', 'tradable emission rights', or other governmental measures) is regarded as a political issue outside the EVR model: in the EVR model costs and eco-costs are treated as separate, different, entities.

3.2 The value, costs and eco-costs of a product.

Now we look into one step of the business chain.

The value ('fair price') of a product is determined by:
✓ product quality
✓ service quality
✓ image.
These 3 components of value are described in more detail by the 'eight dimensions' of Garvin (Garvin, 1988).

The cost-structure of a product comprises:
✓ the purchased materials (or components)
✓ the required energy
✓ depreciation (of equipment, buildings, etc.)
✓ labour.

For each company in the business chain, the tax + profit equals the value minus the costs. Note: In the EVR model interest can be regarded as part of the profit.

The direct eco-costs have been defined as follows:
✓ virtual pollution prevention costs, being the costs required to reduce the emissions in the product chain ('from cradle to grave') to a sustainable level
✓ eco-costs of energy, being the price for sustainable energy sources
✓ materials depletion costs, being (costs of raw materials)x$(1-\alpha)$, where α is the

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[3] Note that the marginal prevention costs have been chosen here as the norm to be able to compare different kinds ('classes') of sustainability issues. For the logic of such a choice and its implications, see Section 2. Basically, the marginal prevention costs are the costs of the last and most expensive measures that have to be taken to bring the economy in a given region to a sustainable level. Marginal prevention costs are not equal to the so called 'external costs', since 'external costs' are related to damage and not prevention.

recycled fraction of materials to make a product (for details on the 'end of life' and recycling phase, see Section 4).

The indirect eco-costs are:
✓ eco-costs of depreciation, being the eco-costs related to the use of equipment, buildings, etc.
✓ eco-costs of labour, being the eco-costs related to commuting and the use of the office (building, heating, lighting, electricity for computers, paper, office products, etc.).

This is depicted in Figure 3.2.
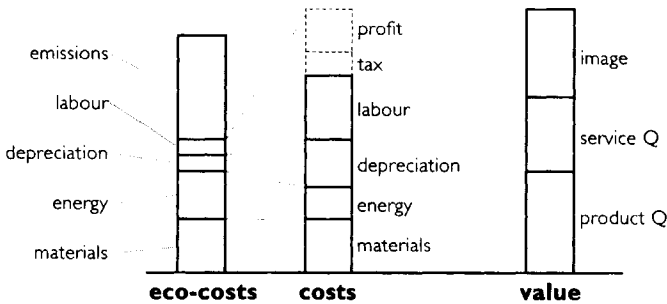
Fig. 3.2: The decomposition of 'virtual eco-costs', costs and value of a product.

Along the busines chain the value, the costs and the eco-costs can be added up, as depicted in Figure 3.3.
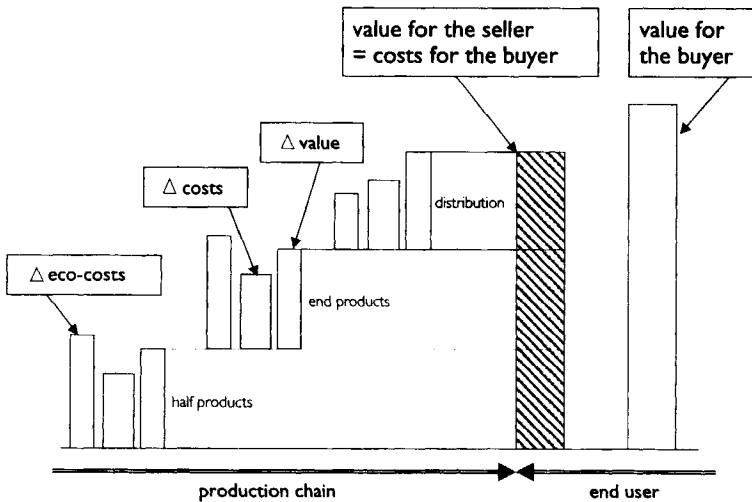
Fig. 3.3: The decomposition of the value in the chain.

Characteristic for each process, product or service is the ratio of the value and the eco-costs. We can define this Eco-costs / Value Ratio, EVR, at every aggregation level of the chain (or 'pool'):

EVR = eco-costs / value.

A low EVR indicates that the product is fit for use in a future sustainable society. A high EVR indicates that the value/costs ratio of a product might become 'less than one' in future (since 'external' costs will become part of the 'internal' cost-structure), so there is no market for such a product in future. Later in this Section we can see how we might apply the EVR model for economic allocation in the LCA of a complex product-service system, but first we will define and describe the eco-costs.

3.3 The components of the eco-costs

As mentioned in Chapter 3.2, we define the eco-costs as the sum of 3 direct (a, b, and c) and 2 indirect (d and e) elements:
a) the virtual pollution prevention costs '99
b) the eco-costs of energy
c) the material depletion costs
d) the eco-costs of depreciation (use) of equipment, buildings, etc.
e) the eco-costs of labour.
All these elements are calculated according to the LCA method, as defined in ISO 14041, as described hereafter.

3.3.1 The virtual pollution prevention costs '99

The virtual pollution prevention costs '99 has already been introduced in the previous Section. The virtual pollution prevention costs '99 have been calculated for a list of 33 materials, see Table 3.1. Note that the data in this Table also includes the pollution prevention costs related to the emissions of the use of energy to produce and transport these materials.

3.3.2 The eco-costs of energy

The calculation method to determine the eco-costs of energy is based on the assumption that fossil fuels have to be replaced by sustainable energy sources. The 'eco-costs of energy' is equal to the costs of the renewable energy system which has to replace the current system. The data which is used, is from the MARKAL database of ECN (ECN, 1998), (Gielen et al., 1998). See also Table 2.2. The results of the calculations for 6 sources of energy are give in Table 3.2. The technologies are selected from MARKAL. These technologies are readily available. It might be, however, that the costs of the proposed domestic sustainable energy systems become gradually lower when the techniques will be widely spread (because of the economies of scale of production costs for a big consumer market).

As an LCA provides data on both energy and its related emissions, the conversion to the related eco-costs has to be done carefully, to prevent counting energy twice. Apply either the energy data and convert it to the eco-costs of energy or the emission data and convert it to pollution prevention costs. In chapter 3.6.2 it is argued that eco-costs of energy have less spread in the calculations (are more accurate) than the pollution prevention costs related to energy. Hence, eco-costs of energy have to be used preferably in the conversion of LCA data to eco-costs. For the processing of materials, however, the use of fossil fuels is often highly integrated in the production process, so that the energy related emissions have to be applied instead.

3.3.3 The materials depletion costs

With regard to the depletion of materials, the main approach in the model is:
- the eco-costs of materials depletion are set equal to the market value of the raw materials when the materials are not recycled
- when a fraction α of the sourced material is recycled, a factor $(1-\alpha)$ is applied to the market value of the raw material for the new product to calculate the eco-costs of materials (for the general concept and its details see Section 4),
therefore

[3.1] *materials depletion costs = 'market value of the raw material' * (1-α)*

The underlying assumption is that the (average) market value of the virgin material for metals reflects the fact whether the material is scarce or hard to find and/or mine (e.g. platinum, gold, silver), or whether that will happen in the foreseeable future[4].

For *plastics* however, the situation is different, since the source of it is crude oil. The average crude oil price was $15.50 per barrel for the period 1994-1998. This price level is also valid for much longer periods in history (for the long term average crude oil prices see www.wtrg.com.), but nobody can predict prices in the future: is $25.00 per barrel realistic? However, it is more in line with the general philosophy of this model to avoid the use of fossil fuels and use biomass instead as source material for plastics. Therefore, in the EVR model the price of feedstock for plastics based on biomass has been chosen for the materials depletion costs. This price is estimated at 0.6 Euro/kg.

The fraction α has to be applied to the materials used for the new product (and not as a fraction of materials from the old product at the End of Life), *after* the upgrading process (if applicable). See Figure 4.5 of Chapter 4.3. Table 3.3 provides the material

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[4] *In theory, one has to apply here the 'present market value' (discounted) of the 'sustainable alternative in the future' for the metal which is depleted, according to the model of Hotelling (Pearce et al., 1990)(Henley et al., 1997). For most of the metals, however, there is no reason to believe that this 'present market value' deviates much from the current average material prices (examples: tin, copper, iron), since the functionality of these materials can be replaced by alternatives which are not more expensive for their specific functions. So the present costs have been taken in this formula.*

depletion costs for 46 metals and 12 other materials. (The basis for these data is the average market value for the period 1988 – 1998, with trend were applicable.)

3.3.4 Indirect eco-cost: the eco-costs of labour

The eco-costs of labour are indirect eco-costs, since labour as such is hardly causing any environmental burden. However, there is some environmental burden related to labour, such as the environmental impacts of heating, lighting, computers, commuting, etc. The calculations of these eco-costs are specific for the type of labour. An example is given here for work in offices.

For the category of personnel in offices an assessment has been made for Dutch employees with average salary costs of Euro 27.500,- per annum (including taxes, insurance and pension funds), having an office space of 33 m^2 (average for the banking and insurance sector):

1. eco-costs of energy per annum per employee (for eco-costs of energy see Table 3.2):
- commuting by car, 20 km for 210 days per year, fuel required:
  840 litres of petrol = 30 (GJ) >   eco-costs = 30 (GJ) x 35.8 (Euro/GJ) = Euro 1074,-
- heating of the office per annum per employee, CBS data[5] for 1994(CBS 1996):
  0.42 (GJ /m^2) x 33 (m^2) = 14 (GJ) >   eco-costs = 14 (GJ) x 9.7 (Euro/GJ) =   Euro 136,-
- electricity for the office per annum per employee, CBS data[5] for 1994(CBS 1996):
  0.85 (GJ /m^2) x 33 ($m^{2)}$ = 28 GJ >   eco-costs = 28 (GJ) x 19.6 (Euro/GJ) =   Euro 549,-
2. eco-costs of the office building per employee per annum:
- total costs related to construction, maintenance and demolition:
  for details see Table 3.4. >   eco-costs = 24 Euro/m^2 x 33 (m^2) =   Euro 792,-
3. eco-costs of office products per employee per annum:
   typical total eco-costs for office products (paper, printing ink, etc.), incl. EoL   Euro 180,-

Total eco-costs labour: Euro 2731,-

Since the average salary costs in this building is Euro 27,500,-: the EVR ratio is here 0.10. Preliminary calculations show that the eco-costs will rise linear with the salary. So a good guess for *labour* in offices is: *EVR = 0.10*. Calculations on labour outside offices (shop floor personnel in factories, sales people, truck drivers, etc. show that the EVR will vary in a range of *0.05 – 0.15*, where the eco-costs of commuting and use of electricity play a rather dominant role. Therefore it is recommended to make an LCA assessment in each typical case.

3.3.5 Indirect eco-costs: the eco-costs of depreciation of production facilities

The eco-costs related to the fact that fixed assets are used to make a product, are indirect eco-costs. The calculations on the eco-costs of the use of fixed assets have the same characteristics as cost estimates for investments: for each individual situation, calculations have to be made on the applied materials and the required manpower.

[5] *The source of the data is the Economic Statistical Institute for The Netherlands, CBS, Voorburg, The Netherlands.*

The basic idea behind the 'eco-costs of depreciation' is that the eco-costs of the production facilities have to be allocated to the products which are made in or with
these facilities. The standard procedure is:

1. Calculate the eco-costs of the production facility.
2. Divide the eco-cost of step 1 by the lifetime T (in years) of the production facility.
   In the EVR model the 'economic lifetime' has to be applied instead of the 'technical
   lifetime', which is 'safe side' since the economic lifetime is usually shorter than the
   technical lifetime.
3. Divide the outcome of step 2 by the number of products N which are produced
   per year.

In formula:

[3.2] $eco\text{-}costs\ of\ depreciation = \dfrac{(eco\text{-}costs\ of\ the\ production\ facility)}{T * N}$

This allocation procedure is similar to the procedure which has been used in the previous chapter for the calculation of the eco-costs of the office building per employee
per annum. Note that different facilities or different subsystems of facilities might have
a different lifetime, T, (see Table 3.4).

Since the EVR model applies the economic lifetime of the facility, equation [3.2] has a
high similarity with the normal, linear equation for production costs related to depreciation:

[3.3] $costs\ of\ depreciation = \dfrac{(value\ of\ the\ production\ facility)}{T * N}$

Combining equation [3.2] and [3.3]:

[3.4] $eco\text{-}costs\ of\ depreciation = (costs\ of\ depreciation) * (eco\text{-}costs\ /\ value)_{production\ facility}$

The meaning for equation [3.4] is that the eco-costs of depreciation can be derived
from the normal costs of depreciation by multiplying it with the EVR of the production facility. In situations where more than one type of product is produced in a complex production system, and where a 'cost break down structure' of the product is
available, equation [3.4] can provide an easy way out of a rather complex allocation
problem. In chapter 3.4 we will show how equation [3.4] can be derived starting from
the definition of allocation as stated in ISO 14041.

Calculations show the following characteristics for the EVR:
- complex machines   0.3
- luxurious buildings (offices)   0.3

- low cost offices	0.4
- processes in stainless steel	0.4
- refineries	0.5
- steel structures	0.6
- warehouses	0.6

In general:
- the use of steel (and other metals) is related to a high EVR (because of high pollution prevention costs, see Table 3.1)
- complex systems have a low EVR (because of a high labour content)

3.4 The EVR for economic allocation in the LCA

The reader may already have got a feel of how to apply the EVR model for economic allocation, and how to derive the "total EVR" of a complex system from the EVRs of the system components.
In this chapter, the EVR is explained in more detail.

An important characteristic of the Eco-costs/Value Ratio of a chain is that the "Total EVR" for a production chain is the *weighted average (on value)* of the EVRs of the steps in that chain. This characteristic is shown in the following equation:

$$[3.5] \quad EVR_{Total} = \frac{\{\sum eco\text{-}costs_n\}}{value_{Total}} = \sum \{ EVR_n * [\Delta value_n / value_{Total}] \}$$

where

$$[3.6] \quad value_{Total} = \sum costs + \sum taxes + \sum profits \qquad \text{(see Figure 3.1, 3.2 and 3.3)}$$

It is obvious that "the chain" (in its one dimensional form) is a drastic simplification of "the real world": in reality production chains are part of production and distribution *networks*. Every actor in the chain is also part of other chains (they have many suppliers and many clients)[6]. In calculation of LCAs this causes the so called "allocation problem": how to allocate the environmental impact of shared use of production facilities, transport and distribution systems, etc.?

The basic methodology for allocation problems in LCAs is dealt with in ISO 14041: *"Where physical relationship cannot be established or used as the basis for allocation, the inputs should be allocated between the products and the functions in a way which reflects other relationships between them. For example, environmental input and output data might be allocated between co-products in proportion to the economic value of the products "*

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[6] *This leads to the concept of the "profit pool" (Gadiesh et al., 1998).*

This methodology can be explained by an example: the indirect environmental impact of building an air plane, allocated to a single trip[7]. The main parameters are:
- the value of a ticket for the single trip, W, of which a part of that value, X, is related to the depreciation (or leasing costs) of the plane
- the value of a plane, Y
- the eco-costs of a plane, Z (calculated from LCA data).

The question is now which part of the indirect environmental impact of building a plane, Z, has to be allocated to the trip. Applying economic allocation:

$$[3.7] \; EI = \frac{X}{Y} * Z = \text{"the economic proportion"} * \text{"Environmental Impact"}$$

Where EI is the indirect environmental impact allocated to the ticket, which can be written as:

$$[3.8] \; EI = \frac{Z}{Y} * X = EVR * \text{"part of the value of the ticket related to the depreciation of the plane"}$$

Equation [3.8] shows how the EVR model can be used for economic allocation in a complex LCA, starting with a 'cost-breakdown structure'. Especially in cases when proportions of weight are not known directly, which is often the case for services, the EVR model is a powerful tool. Note that equation [3.4] and equation [3.8] are of the same nature.

In the example, equation [3.8] is applied to an 'indirect' environmental impact. Equation [3.8] can also be applied to situations of 'direct' impact (e.g. for allocation of the fuel to one passenger). In most of the situations of 'direct' impact, however, the physical relationship is known as well, in which cases the eco-costs have to be determined on that direct physical relationship, according to ISO 14041. Although the authors of the ISO 14041 define economic allocation as a 'last option' (to be avoided, if possible) there is no need to avoid economic allocation in cases where the ratio between 'value' and 'kilograms' is fixed [8], since the ratio between eco-costs and value, the EVR, is fixed then as well. So it is a prerequisite for EVR calculations that a specific EVR has to be independent of the size (weight, volume, time, etc.) of the functional unit of the element in the LCA. Under this condition, the EVR can be used for direct impacts as well, instead of the eco-costs / weight ratio, which appears extremely practical in many cases.

[7] There is no simple physical relationship to base the allocation on for many reasons. The major two reasons are: Planes transport passengers as well as freight (in the same plane on the same trip). How to allocate (split) between passengers and freight? Based on volume or on weight or any combination of both?
One plane will make many trips during its lifetime, all over the world. There are trips ('legs') with high occupancy rates and trips with low occupancy rates. How to cope with these differences during the lifetime?
[8] Under such conditions, the 'economic proportion' in equation [3.7] equals the 'physical proportion'.

The first example is on how to apply the EVR in the case of a service function (a transport chain), where economic allocation plays a major role. This example is given in Table 3.5. In the example of the transport function of Table 3.5, only the 'one way' packaging can directly be linked to the LCA. All other elements in the chain share with other chains (even fuel, since the truck is normally only partly loaded by other freight on the trip back). It is feasible here to establish all 'physical relationships', however, the relationships are of an extremely complex nature, so a computer programme has been written to calculate the eco-costs. With the same program structure, costs are being calculated as well. Analysing the output, it has been concluded that all the activities can be grouped in 'subsystems' (9 in total), since they have the same, constant, EVR (See Section 6). Table 3.5 shows that the calculation of the total eco-costs for the defined function becomes extremely simple, when the values (prices) for the main activities are known, applying these EVR data. The outcome is within 3% of the outcome of the computer calculation based on the 'physical relationships'.

The second example is on how to apply the EVR model in the design stage of a product, in this case a warehouse, see Table 3.6 and 3.7. In Table 3.6 the classical LCA is provided on the basis of materials required to build the warehouse. This methodology is suited for the situation that the detailed design of the warehouse is finalized (in The Netherlands, a powerful computer calculation model is available for such an analysis: Ecoquantum). However, in the preliminary design stages, the exact amount of materials is not yet known. In that stage the EVR method is more applicable to analyse different alternatives for the design, see Table 3.7 (the designer has to try to fulfil the design requirements by applying elements with the lowest possible EVR values).

Table 3.6 and 3.7 provide an analysis on the same warehouse design. The results, however, in terms of eco-costs are not exactly the same: the differences in both cases are caused by the use of different sources of LCA data (Note that LCA emission data can differ by a factor 2, or even more, for the same type of materials, because of differences in applied processes and/or practices !)

3.5 The EVR and the virtual eco-costs '99 for industrial activities

Similarly to the calculations on the pollution prevention costs of materials (Table 3.1), calculations have been made on these costs of industrial activities. These calculations are based on an extensive measurement programme on the emissions of industrial sectors in The Netherlands. Furthermore the eco-costs of energy have been calculated on the basis of the energy consumption of these industrial sectors, and the eco-costs of depreciation and labour have been estimated on financial data on these sectors. The results of the calculations are provided in *Table 3.8*. To calculate the data of Table 3.8, the measured industrial pollution in 1995 (VROM, 1997) has been compared with general statistic data on these industries for 1995 (CBS, 1997). Basically, the EVR data of Table 3.8 form the link between the LCA-based approach and the 'input-output table' based approach of macro economic environmentalists.

3.6 Discussion

3.6.1 Eco-efficiency

Since the EVR links the 'value' with the 'ecological impact', the EVR is also a parameter for the eco-efficiency as defined by the WBCSD. We propose the following equation (see Figure 3.4):

$$[3.5] \quad eco\text{-}efficiency = \frac{(value - eco\text{-}costs)}{(value)} \quad , or \ eco\text{-}efficiency = 1 - EVR$$
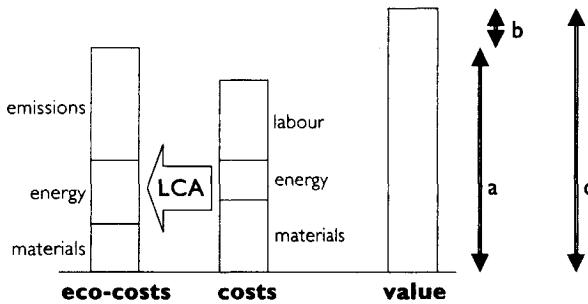
Fig. 3.4: The definition of eco-efficiency in the EVR model: eco-efficiency $= \dfrac{b}{c}$

Note that the eco-efficiency is:
- negative when the eco-costs are higher than the value, or where EVR > 1
- 0% when the eco-costs are equal to the value, or when EVR = 1
- 100% when there are no eco-costs, or when EVR = 0.

3.6.2 Accuracy

Rather than accuracy, practical choices on system characteristics and system boundaries are the major concern in an LCA (What is included? Which processes? Industrial averages or best practices? etc.). Sensitivity analyses showed that these choices are dominant in the EVR calculation model (as they are in other LCA-based models applying a single indicator).

The 'value' in the equation is not as vague as many non-specialist would suspect: in the EVR model, the value is defined as the 'sales price' within the business chain and the 'fair price' in the consumer market, which are quite well determined in practice.

A way to analyse the topic of accuracy is to study the variance of LCA data and sales prices within Europe. Two examples:
- For a specific design of a solid or corrugated board box, the best practice versus the 'worst practice' in terms of 'clean production' differs more than a factor four

within Europe. The value (price) is in this market segment hardly higher than the production costs. Within Europe these production costs differ not more than approximately 20%. Therefore the value is quite accurate in comparison with the eco-costs.

- For electricity, production in Holland is a factor 2 cleaner than in Portugal. In countries with hydroelectric power as Norway, emissions are a factor 100 less than in Holland. (Rombouts et. al., 1999) Prices, however, differ not more than 30% within the EC. Again, the value is quite accurate in comparison with a single indicator for emissions.

Emissions of energy production vary enormously with the choice of type and grade of the fossil fuel. In the eco-costs model, energy from fossil fuels is replaced by renewable energy, rather than preventing the emissions from these fossil fuels. The accuracy of the costs estimates for renewable energy systems is estimated at 30%, which is by far better than the spread in emissions of energy from fossil fuels.

The fact that the EVR is dimensionless, means that the EVR model is relatively robust with regard to exchange rate fluctuations or inflation of currencies.
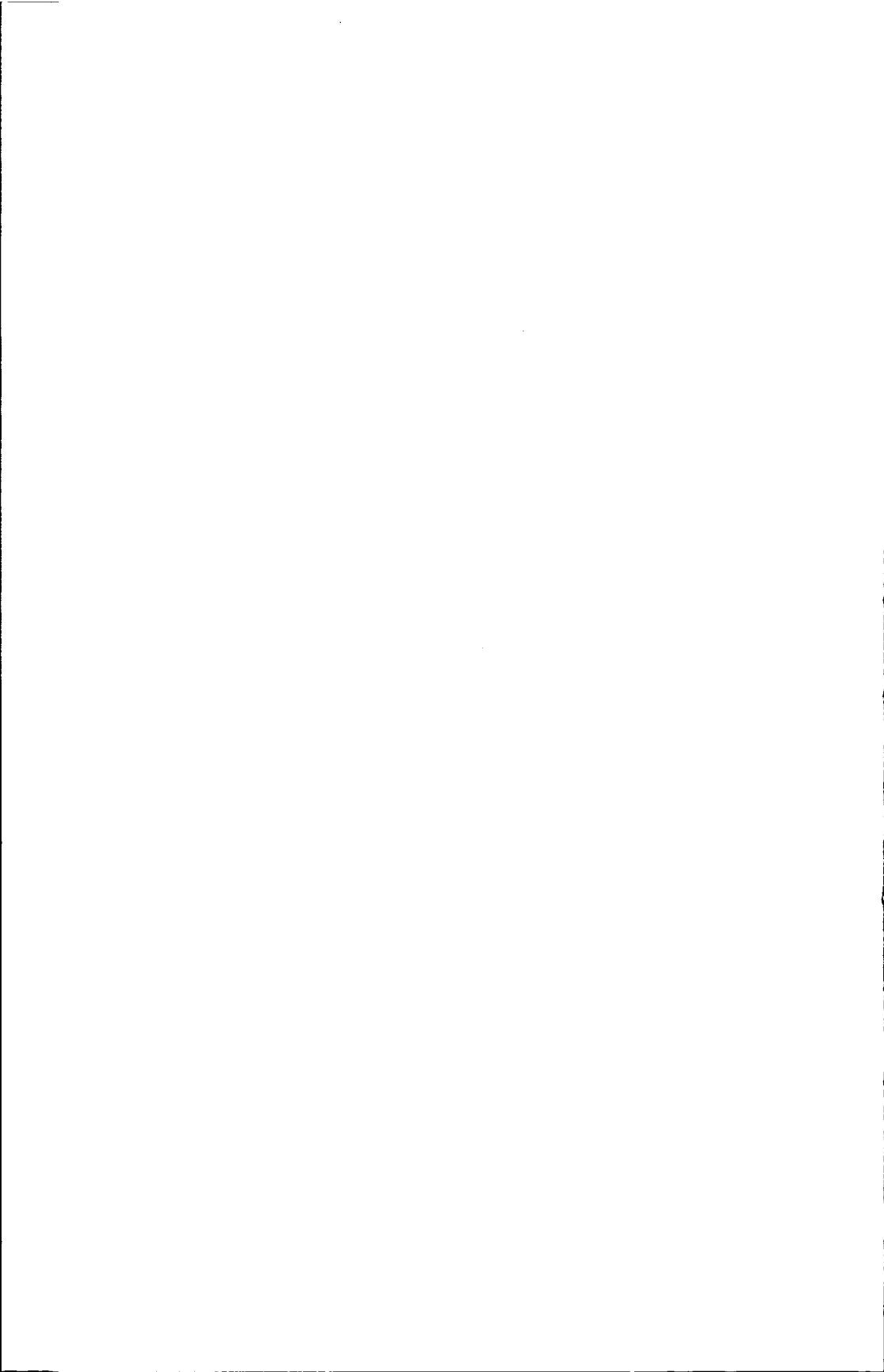
4. Allocation in recycle systems: an integrated model for the analyses of eco-costs and value

A prioritization system: 'De Delftse Ladder' ('The Delft Order of Preferences')

Abstract

This Section deals with research task 4: make a new model for the End of Life stage of complex products.

'Design for Recycling' and dematerialization by enhancing the durability of products are major aspects of the quest for sustainable products. This Section presents an LCA based model for the integrated analyses of the product chain, its recycling systems and its waste treatment systems at the 'End of Life' stage. The model is an extension of the EVR model, but can also be applied to other life cycle interpretation systems, since the model as such is not restricted to the use of the eco-costs as a single indicator.

The model has been developed to evaluate the design alternatives of complex products like buildings and cars. These products comprise several subsystems, each with its own special solution at the End of Life stage: extending of the product life, object renovation, re-use of components, re-use of materials, useful application of waste materials, immobilization with and without useful applications, incineration with and without energy recovery, land fill.

Since complex product systems always comprise a combination of these design alternatives, a methodology is given to calculate and allocate the eco-costs of the total system in order to select the best solution for sustainability. The methodology is characterized by:
- *a main allocation model of the recycling flow based on physical relationships*
- *a strict separation of the market value, the costs and the eco-costs in the system*
- *a main allocation model for extension of lifetime based on 'depreciation of eco-costs', parallel to economic depreciation.*

4.1 Introduction: Current issues with regard to the End of Life stage of products

4.1.1 Complexity

The End of Life stage of products is a rather complex stage. Products are collected and dismantled, materials are separated and upgraded, waste is incinerated or dumped, toxic materials are immobilized or incinerated. In terms of the LCA, it is a problem that materials of products are combined with materials of other products, which causes fundamental problems with regard to allocation (Klöpffer, 1996) (Ekvall, 1997). The economics in the End of Life stage is rather complex as well, since *products* and *materials* in the End of Life stage often have a negative market value (price) as such. The *activities*, however, to recycle these products and materials in an environmentally correct manner, have a positive added value for our society as a whole. This results in a situation where the 'free market' has to be restricted in many ways by governmental regulations (e.g. prohibition of dumping certain materials and/or products in land fills), and where the government has to force industry to recycle their products in a correct manner.

In terms of the EVR model (See Section 3 for a detailed description), the aforementioned complexity means that:
- the allocation model of the End of Life stage has to be defined in an unambiguous way
- the 'value' system in the End of Life stage has to be determined.

4.1.2 Three common ways of looking at the End of Life of products

To unravel the complexity, we may distinguish 3 common ways of looking at the EoL (the 3 EoL paradigms):
- 'the cycle'
- 'the chain'
- 'the cascade'.

'The cycle' is depicted in Figure 4.1, being the idealists way of "how it should be": when 100% of the products and/or materials are recycled, all problems of materials depletion and land fill are resolved. Modelling the End of Life as one single recycle loop, however, does not cope with two important aspects of the reality:
1. 'the second law of thermodynamics', requiring an 'upgrading' activity and requiring 'bleed flows' to cope with degradation, contamination and dilution of materials within the loop
2. 'the many lives of recycled materials', i.e. materials do not stay in one product loop, but switch to other product loops ('cascading' down to other life cycles).
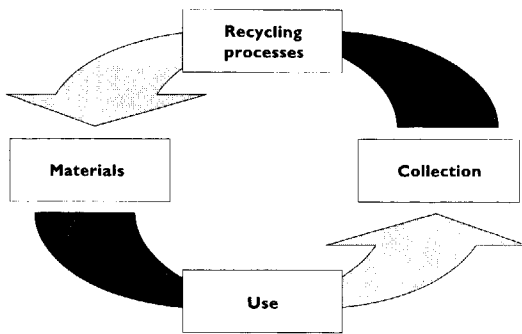
Fig. 4.1: The End of Life system from the point of view of idealists: 'the cycle'.

'The chain' is depicted in Figure 4.2, being the way product designers and engineers approach the problem of EoL. The recycling systems as such (after the separation step) are normally not included in the product analyses. 'The chain' is the way EoL is configured in design tools like Simapro, Ecoscan and in the EPS system.

The main focus within this paradigm is twofold:
A. try to apply recycled materials for construction elements of the new product or structure
B. make it technically feasible (easy) to disassemble or dismantle the product or structure: 'design for recycling' (the 'separation' step in Figure 4.2).

Depicting End of Life as 'a chain' does not cope with two important aspects:
1. the recycling activities as such cannot be analysed (alternative systems for transport and upgrading after the separation step), since recycling systems normally combine many 'chains'
2. the sense or nonsense of recycling activities as such, with regard to the general subject of sustainability, cannot be analysed (questions like: is it wiser to recycle a certain type of plastic, or burn it?).
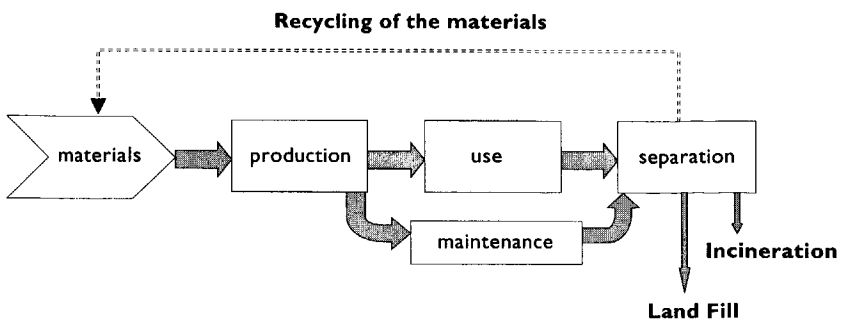
Fig. 4.2: The End of Life system from the point of view of product designers: 'the chain'.

'The cascade' is depicted in Figure 4.3, being the way most of the business managers as well as LCA-specialists approach the problem of End of Life. The main focus within this paradigm is " can we do something useful with the old product, or, do we have a 'second life' for the old materials". In the strict sense, 'the cascade' is not a form of recycling, but rather a form of re-use of the degraded materials itself (examples are waste paper, fly-ash, crushed stones and crushed concrete). The cascade is regarded as the fundamental way to optimize the use of resources (Sirkin et al., 1994).

The cascade has triggered many proposals and debates among LCA-specialists on the subject of allocation:
1. Has the environmental burden related to use of virgin materials to be allocated to the first product only, or has this environmental burden partly to be allocated to the second and third use for products as well? (In The Netherlands this allocation to a second and/or third product life is called 'estafette method', referring to relay races)
2. Given the fact that the End of Life activities (like separation, transport and upgrading) are causing environmental burden, which of these activities have to be allocated to which product?
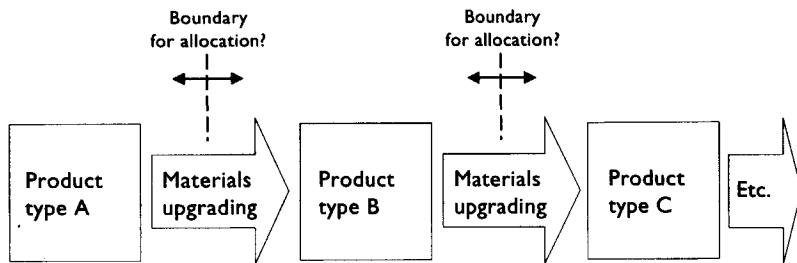
Fig. 4.3: The End of Life system from the point of view of LCA experts: 'the cascade'.

4.1.3 Order of Preferences of End of Life solutions in The Netherlands ('the Ladder of Lansink')

Given the complexity of the EoL systems, the government of The Netherlands adopted an order of preferences of EoL solutions on which to base the governmental policy. This is a sort list of five EoL solutions, the so called 'Ladder of Lansink':
1. re-use of the product (example re-usable crates for transport of consumables)
2. re-use of the materials of a product (example recycling of glass and metals)
3. incineration with energy recovery
4. incineration without energy recovery
5. land fill.

This order of preferences for policy making of the Dutch government was implemented in 1979, and is still the basis for decisions on regulations, legislation, taxation

and subsidies. Designers of a so called Product-Service System (PPS) think along the same lines:

a. try to bring the recycling activity within the PPS and "close the loop" (create 'the cycle')

b. when a. is not a practical solution, create 'the chain' with maximum materials recovery

c. when b. is not feasible (because of severe degradation) try to create 'the cascade' + incineration with energy recovery

d. incineration without energy recovery and landfill has to be avoided.

Although the list of preferences has its basic logic, and although it served successfully as a catalyst for Dutch policy making for two decades, the need for a better system is felt under a vast majority of the people involved:

- there is a need for a more refined list of preferences
- there is a need for a calculation model to check which of the EoL systems on the list is the best practical solution for a specific case in terms of sustainability[9].

In Chapter 4.3 such a new refined list of preferences is proposed, and it is shown how to make calculations on the eco-costs and the EVR in the chapters thereafter. First, an overview of the existing theories on allocation in cascade systems will be provided in the next chapter.

4.2 Existing theories for allocation in cascade systems

As mentioned in Chapter 4.1.3, the main debate on allocation of EoL activities concentrates on 'the cascade' of Figure 4.3. The main question is where to allocate the environmental burden related to the primary production of materials, the recycling activities, and the final waste treatment.

The classical approach of LCA practitioners of separating the assessment of the product chain and the assessment of the recycling system is inappropriate: innovative designs of product-service systems require an integrated assessment of both the product chain and its recycling systems. This becomes even more relevant in cascade systems.

The norm ISO 14041 provides a framework on how allocation problems should be tackled. It describes a three step procedure with regard to allocation[10].
As a first step, allocation should be avoided where possible (by dividing the process in sub processes or by expanding the product system). As a second step, when alloca-

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[9] Note that, for a specific case, the sequence of preferences of the best practical solutions in terms of sustainability can deviate from the general sequence. An example is the best choice of transport packaging for medium distances, where re-use of the product (the re-usable crate system) is less favourable than re-use of material (the board from recycled paper system) because of the extra return transport of the empty crates.

[10] Allocation is defined in this ISO as: partitioning the input and/or output flows of a process to the product system under study. For an extensive analysis on the subject of allocation, see (Frischknecht, 1998).

tion cannot be avoided, allocation has to be done in a way which reflects an underlying, causal, physical relationship. The third step is about 'other relationships' such as economic value. Some authors argue that economic allocation cannot be avoided here, since neither of the two first steps are feasible, and since the boundary line in Figure 3 always leads to arbitrary choices (Lindfors, 1995) (Lindeijer et al., 2000) (Werner et al., 2000) (Ekvall, 2000). The question is, however, whether economic allocation, based on the - heavy fluctuating - market prices of recycled materials, will lead to better results than the simple methods which were originally proposed: "shifting the secondary materials outside the system boundaries" (Klöpffer, 1996), or the "simple cut-off method", where a product made out of primary materials carries the environmental burdens of those primary materials and a product made out of secondary materials carries the environmental burdens of the recycling activities of those secondary materials (Ekvall, 1997).

The EVR model provides a method for economic allocation, but economic allocation can only be applied when specific criteria have been fulfilled (see Section 3):
- relatively stable prices in a transparent, free, and open market
- a linear relationship between market value (price) and mass, volume and/or time.
It has to be emphasised here, that these criteria are not fulfilled for the economic allocation models which have been proposed by CML (Lindeijer et al. 1999), since:
- prices for products like scrap and waste paper are highly volatile (unstable)
- the markets for these waste materials are highly influenced by governmental policies
- there is no simple, linear, relationship between market value (price) and mass.

The economic allocation model which has been proposed by CML (Lindeijer et al., 1999) is characterized by the fact that the boundaries for allocation shift with the market price of the waste materials. The EoL activities are being allocated to the next product, when the next product pays for the waste (when the waste material has a positive value). This system is depicted by the example on 'a house to be demolished and processed into road building material', see Figure 4.4. In Figure 4.4, the environmental burden of the activities in the grey blocks is allocated to the road, the environmental burden of the other activities is allocated to the house.

In Figure 4.4, four situations have been depicted. Quoted from (Lindeijer et al., 1999):
" ...
- variant A: waste flow value positive from building, and hence even more positive after processing and in road structure
- variant B: waste flow value zero from building, value positive after processing and in road structure
- variant C: waste flow value negative from building, value negative after processing but positive in road structure
- variant D: waste flow value negative from building, value negative after processing and the road structure has a waste management function as a co-product
... ".

Variant A | house → (+) → | EoL processes | → (+) → | road

Variant B | house → (0) → | EoL processes | → (+) → | road

Variant C | house → (-) → | EoL processes | → (+) → | road

Variant D | house → (-) → | EoL processes | → (-) → | road
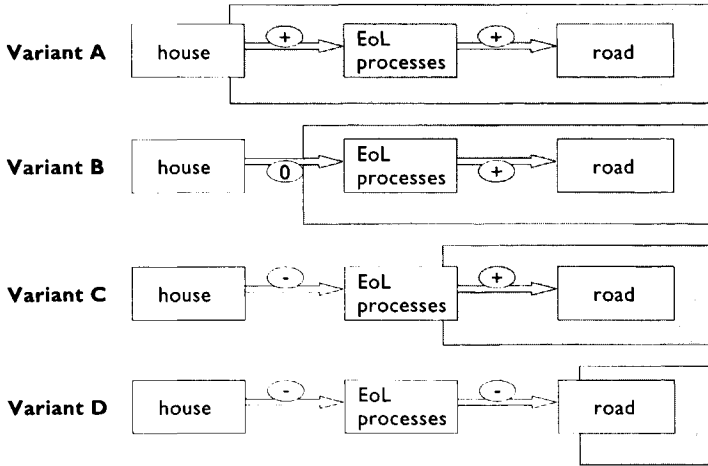
Fig. 4.4: The CML allocation model for the situation where materials of a house after demolition are used in road construction, from (Lindeijer et al., 1999), simplified.

The basic idea of such an allocation model is that 'the house' has to benefit from the fact that there is a useful appliance of its waste (the designer of the house should be influenced by the LCA to use materials which can be re-used in other products or structures). The 'estafette' allocation model (estafette = relay race) of (Seijdel, 1994) and the ISO option of 'the number of subsequent uses' (ISO chapter 6.4.3) have the same intention: taking the full burden away from the first product.

The main disadvantage of the allocation model of CML is that the value of the waste material is not known at the moment that the house is designed and built: often more than 40 years before the moment of demolition! So at the design and building stage of the house, the boundaries for allocation are not known, which is a rather unpractical situation.

There is also a methodological flaw in the CML system, caused by the fact that it is often the 'bundle of costs and benefits', and/or the governmental regulations, that influences the economic decisions. It is not the price of the waste materials as such which influences the economic decision. In the example of the house, the reason for demolishing a house is often the fact that the value of the ground area is more than the value of the house. The EoL activities are then a co-product of another activity: project development. The EoL activities are 'subsidised' then by the main product (being the creating of ground area). The value of the waste is hardly influencing the economic decision in such cases. So there is no reason at all to give the economic value of waste materials an important factor in the allocation model.

4.3 The End of Life system of the EVR model and a new order of preferences of EoL solutions ('the Delft Order of Preferences')

In Chapter 1 it was concluded that EoL systems are complex, and the three para-digms (the cycle, the chain and the cascade) each cover only a part of the real prac-tice. In Chapter 2 it was concluded that the existing proposals for EoL allocation, based on the market value of recycled materials, do not fit the reality.
Therefore, a methodology has been developed, which:
- reflects the underlying, causal, physical relationship (step 2 of ISO 14041) of the materials flow in the recycling markets,
- can be regarded as an enhancement of early proposals in this field (Klöpffer, 1996) (Ekvall, 1997) (Kim, 1997),
- keeps the environmental burden, the market value and the costs in the chain strictly separated,
- deals not only with recycling, but also with enhancement of the lifetime of a product.

The way that the EVR model deals with End of Life and Recycling is depicted in Figure 4.5. This Figure depicts the major types of End of Life treatment and types of recycling. It is developed to describe and analyse the various kinds of complex mod-ern life cycles of products, buildings, manufacturing plants, civil structures, etc.
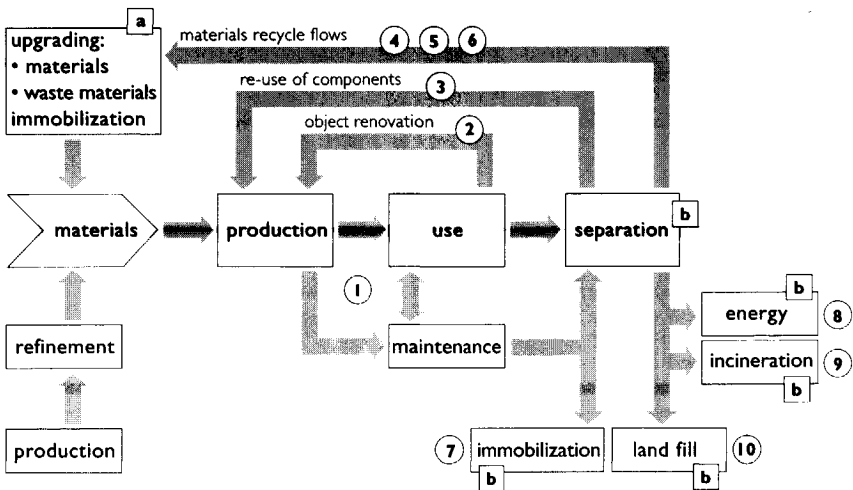
Fig. 4.5: The flow of materials in the Life Cycle.

The numbers in Figure 4.5 relate to the "Delft Order of Preferences", a list of the 10 major systems for End of Life used for structured and systemised analyses of (combi-nations of) design options:
1. Extending of the product life
2. Object renovation

3. Re-use of components
4. Re-use of materials
5. Useful application of waste materials (compost, granulated stone and concrete, slag, etc.)
6. Immobilization with useful application
7. Immobilization without useful application
8. Incineration with energy recovery
9. Incineration without energy recovery
10. Land Fill.

It is important to realise that for big, modular objects (like buildings), there is not "one system for End of Life" but in reality there is always a combination of systems. The two basic rules for allocation in the EVR model are:
- Costs and eco-costs of all activities marked with 'b' are allocated to the End of Life stage of a product (transportation included).
- Costs and eco-costs of all activities in the block marked with 'a' are allocated to the material use of the new product (so are allocated to the beginning of the product chain).

There are many reasons to allocate the activities in the block marked with 'a' to the new product, and the activities in the blocks market 'b' to the old product. Three major arguments:
- Physical tracing of recycled material flows between the "separation step" and the "upgrading step" is often impossible (e.g. for recycled materials like metal scrap and waste paper there is a global trade with large stocks of several grades, so there is no direct physical relationship for those materials between the old product and the new product).
- The processes to upgrade or blend the different grades of recycled materials are often directly related to the use in the new product, sometimes these processes are even integrated in the making of the new product (e.g. paper from recycled paper mills, steel from the Basic Oxygen Steelmaking process, etc.).
- For products with a long lifetime, other allocation models lead to wrong conclusions (Gielen, 1999)[11].

In fact, the allocation of the activities of block 'a' to the new product is well in line with the allocation procedure in ISO 14041. The recycling activity has been split in subsystems type 'a' and type 'b' (step 1 in the procedure) and the subsystems type 'b' have been allocated to the old product and the subsystems type 'a' have been allocated to the new product. This is according to the physical relationship, in line with the ability to trace materials flow in the recycling loop.

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[11] *Example: when the average lifetime of a car is 10 years, and when the production of cars has doubled in the past ten years, 45% recycled steel can be used in new cars when 90% of the steel of old cars is recycled. It is obvious that the fact that we need 55% virgin material for new cars is more relevant for our society in terms of material depletion and CO_2 emissions, than that we recycle 90% of the old cars.*

In line with the aforementioned allocation strategy, the 'bonus' to use recycled materials is taken at the beginning of the product chain, where the new product is created. Material depletion is caused here when 'virgin' materials are applied, material depletion is suppressed when recycled materials are applied. The eco-costs of materials depletion are defined by the costs of the fraction 'virgin' materials, $(1 - \alpha)$, which are used for the new product. In formula:

[4.1]   *eco-costs of materials depletion = (costs of raw materials) * (1-α)*

where α is the fraction of used materials for the new product which stems from 'recycled' material (when upgrading is required, *after* the upgrading step). See Chapter 3.3.3.

The 'separation' block in Figure 4.5 comprises a chain of activities for most products. To end up with the best grade and the best purity of recycled materials, the separation step of products has normally to be organized in at least three steps:
1. dismantling of the product in components
2. demolishing the components (in a shredder)
3. separation of the output of the demolishing step (by a magnet, by eddy current, by air flow, etc.).

For buildings the same principle applies: dismantle the building first (taking out the wood, glass, cables, metals, etc.) prior to demolishing the building. The quality (purity) of recycled materials is then much better, compared with the 'classical method' (demolishing as the first step and separation afterwards).
This has two consequences for the future building industry:
- the design of a building has to be such that the building can easily be dismantled in order to be able to separate the several building materials ('design for recycling'), like 'design for recycling' as it is common practice now for consumer electronics and cars
- low capacity, transportable, processing equipment for 'separation' and crushing at the site of the old building is to be preferred instead of processing in big, centralized, separation plants, in order to avoid contamination and degradation of recycled materials during the materials handling, transport and storage prior to processing.

4.4 The eco-costs of End of Life and recycling activities

4.4.1 The eco-costs of End of Life of a product

All of the activities of Figure 4.5 have their emissions, use of energy and use of additional materials (e.g. the equipment which is used), so all of these activities have eco-costs. As it has been mentioned in the previous chapter, eco-costs of all activities (transportation included) marked with 'b' are allocated to the End of Life stage of the old product. In formula:

[4.2]   eco-costs of EoL = $\sum$ (eco-costs of activity type 'b')

Note that there is no 'estafette (relay race) effect' in the allocation model of the EVR model because of the clear division between activities 'b', to be allocated to the EoL of the old product, and activities 'a', to be allocated to the new product.

With regard to the summation of eco-costs according to equation [4.2], the analysis of two blocks of activities in Figure 4.5 need extra attention:
- incineration with energy recovery (block number 8)
- land fill (block number 10).

For incineration with energy recovery, there is a surplus of energy in the Life Cycle, which results in negative eco-costs of energy in equation [4.2], since energy is 'exported' to other products.

For 'Land Fill' it has been decided by the Dutch government that Land Fill is not a sustainable solution for waste treatment, and therefore has to be avoided (prevented)[12]. Consequently, the EVR model introduces the 'eco-costs of Land Fill', being the costs of prevention of Land Fill. The 'last' main prevention measures for Land Fill to reach the target (the 'marginal prevention costs') are:
- making compost of bio waste: processing costs 80 Euro per 1000 kg
- incineration of domestic waste in an environmentally acceptable way: processing costs 100 Euro per 1000kg
- recycling building materials: extra costs of separating materials at the EoL (partly 'dismantling' instead of total 'demolition' of the structure) is less then 100 Euro per 1000kg in most cases.
Consequently, the 'eco-costs of Land Fill' have to be set at 100 Euro per 1000 kg, being the costs of these marginal prevention measures to reach the target.

It has to be mentioned here that the target setting for Land Fill in The Netherlands has been a political choice: the Dutch society is apparently "willing to pay" about 100 Euro per 1000kg in order to minimize land fill to the level of about 4% of the solid waste. In fact, the 4% target is a result of what is considered as feasible in the techni-cal/economical sense[13]. It is obvious that regions which are less densely populated will tend to take less expensive measures to prevent Land Fill (e.g. they will not be pre-pared to invest in incinerators and large scale compost production). Or should these regions apply the 'best practices'? (see also the 'call for comments' in Annex 2b)

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[12] The governmental policy in The Netherlands is to restrict Land Fill. In 1996 14% of the total waste flow was Land Fill, the target for 2010 is 4% ! Land fill for toxic materials is forbidden by law.

[13] This situation is different from the setting of norms for emissions in Section 2. For emissions, the Dutch government has based their norms on the 'negligible risk level' for concentrations (in air and in water) and the corresponding 'fate analyses' (the link between concentration and emissions). Although there are many scientific disputes over these kind of calculations, they are less arbitrary than just the 'political will'.

4.4.2 The eco-costs of using recycled materials for a product

Scrap metal, waste paper, waste glass, waste plastics, waste wood, etc. are regarded as the source for 'recycled' materials (as metal ore, pulp for paper, etc. is the source for 'virgin' materials). The eco-costs of the processes to make the new material from the waste material is allocated to the material which is used in the new product. In the EVR model, the eco-costs of materials of a new product are calculated according to equation [4.3]:

[4.3] $eco\text{-}costs\ of\ materials = \sum (eco\text{-}costs\ of\ energy + pollution\ prevention$

$costs)_{upgrading\ of\ recycled\ materials} + \sum (eco\text{-}costs\ of\ materials\ depletion + eco\text{-}costs\ of$

$energy + pollution\ prevention\ costs)_{virgin\ materials}$

In most cases virgin materials require more energy and cause more pollution than recycled materials (e.g. metals and glass). See also Table 3.1[14].

For situations of combined material production, such as in the Basic Oxygen Steelmaking process, equation [4.3] can be combined with equation [4.1] and written in the form of equation [4.4]:

[4.4] $eco\text{-}costs\ of\ materials = \sum (costs\ of\ raw\ materials) * (1-\alpha)$

$+ \sum (eco\text{-}costs\ of\ energy + pollution\ prevention\ costs)_{processing\ of\ all\ materials}$

where α is the fraction of material for the new product which stems from 'recycled' material (*after* the processing step!).

4.4.3 The eco-costs of recycling

In the previous Chapters 4.1 and 4.2, the way of calculation and allocating eco-costs of the recycling loop has been dealt with. This approach was focussed on the 'eco-costs of a product'. In this chapter we will deal with the subject of the 'eco-costs of recycling', and the ability to analyse ('closed loop') recycling systems as such.

To calculate the eco-costs of recycling the following activities are included, see Figure 4.5:
- all activities type 'b', including the required transport and storage
- all activities type 'a', including the required transport and storage.

For calculation (comparison) of recycling systems, the following assumptions are made:
- the recycling system is 'closed loop' (the materials of the EoL of a product are

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[14] Note that in most of the LCA data on materials, the pollution data include pollution from the use of energy. In those cases energy must not be counted extra in the formula for the total eco-costs, to avoid counting energy twice. See Section 3.

recycled and used for a new product of the same type)
- time (material hold-up) is not taken into account
- when a material fraction α in the new product stems from recycling, a material fraction $(1 - \alpha)$ in the new product stems from 'virgin' material, and a fraction $(1 - \alpha)$ ends up in one of the following EoL systems (see the "Delft Order of Preferences", Figure 4.5, Chapter 4.3):
  - Immobilization without useful applications
  - Incineration with energy recovery
  - Incineration without energy recovery
  - Land Fill.

Note that degradation of the product is taken into account by the 'bleeding' of a small fraction to either of the following EoL systems: Immobilization without useful appliances, Incineration, or Land Fill. This 'bleed' of material will lead to virgin material entering the life cycle loop and will keep the grade in the recycling loop at an acceptable level.

The 'eco-costs of a recycling system' are 'virtual', since the aforementioned assumptions hardly exist in real life (recycling systems are not 'closed loop' in the real sense of the word). The total eco-costs of recycling are defined as (see Figure 4.5 for activity type 'a' and type 'b'):

[4.5] eco-costs of recycling = $\sum$ (eco-costs of activity type 'b') + $\sum$ (eco-costs of activity type 'a')

When a classical analysis is made of recycling systems as such (without integration with product chains), the benefits in terms of 'avoided eco-costs' might be taken into account. These benefits relate to the fact that less 'virgin' materials are used (resulting in less materials depletion and normally less pollution and less use of energy at the materials production stage).
When α is the fraction of material of the new product which stems from 'recycled' material, the 'net eco-benefit of recycling' can be defined for the total recycling system as:

[4.6] 'net eco-benefit of recycling' = $\sum$ {(a + b + c) − (d + e) + f } * α

where:
a = (eco-costs of materials depletion) $_{\text{at 100\% virgin material}}$
b = (eco-costs of energy) $_{\text{at 100 \% virgin material}}$
c = (pol. prev. costs) $_{\text{at 100\% virgin material}}$
d = (eco-costs of energy) $_{\text{at 100\% recycled material}}$
e = (pol. prev. costs) $_{\text{at 100\% recycled material}}$
f = (eco-costs of immobilization, incineration or Land Fill).

The 'net eco-benefit of recycling' ranges from zero ($\alpha = 0$, no recycling) to a maximum ($\alpha = 1$, 100% recycling)[15], where $\alpha = 1$ is not feasible because of the 'second law of thermodynamics'.

The purpose of equation [4.6] is to bring the positive effect of re-using materials within the boundary limits of the analysed recycling system. When 'total loops' or 'total systems' are to be analysed (when the product chains are included within the boundary limits), equation [4.6] must *not* be used, to avoid 'double counting' of the 'avoided eco-costs'.

4.5 The Value and the EVR of EoL and recycling systems

4.5.1 The value in the recycling loop

The economics in the End of Life stage and the economics of recycling are rather complex, since, in most cases, products and materials in the End of Life stage have a negative market value (companies who take away discarded products are paid for it). People can earn money by keeping these products in stock, resulting in an enormous hold-up of discarded products world wide, and resulting in a certain pressure to get rid of it in an illegal way. Therefore, the "free market of discarded products" has to be restricted in many ways by governmental regulations (e.g. prohibition of dumping certain materials and/or products in land fills), and the government has to force industry to recycle their products in a correct manner.

The services (activities) to recycle these products and materials in an environmentally correct manner have a positive added value. Within the framework of regulations and joint agreements between government and industry (the Dutch 'convenants'), a free market of recycling activities can thrive. A special problem, however, for the free market of recycling is the fact that recycled materials fluctuate heavily in price. This instability of prices results from the fact that:
- price speculation in recycled products is cheap (because of the negative investment in stock)
- some governments in the western economies subsidize processing of waste materials, while others do not (sudden introduction of subsidies, regulations and the like, disturb markets and market prices)
- some countries in the Far East buy waste materials (like waste paper) in enormous quantities at one time (transport of waste materials from Europe to the Far East is extremely cheap because of the surplus of empty containers returning to the Far East).

The aforementioned situation leads to the following consequences:

[15] *A similar model is proposed for 'environmentally weighted recycling quotes', to replace the 'material recycling efficiency' used by several member states in the EU, which describes the performance of recycling systems (Huisman et al., 2000a) (Huisman et al., 2000b).*

- the negative market value of discarded products and materials is indirectly deter-
  mined by the governmental regulations and levies on waste treatment, which are a
  result of the 'willingness to pay' to avoid Land Fill
- the market value of recycled materials (after upgrading) might be less than the
  total costs of recycling
- the recycling activity is economically feasible when the added value of the recycling
  activity is more than the added costs.

*The analyses of eco-costs, costs and value of recycling chains must be done with great
care. The best approach is to keep these 3 elements strictly separated along the chain,
avoiding the total picture getting blurred by mixing up the economic and environmental
aspects.*

The value and the costs along the recycling chain are depicted in Figure 4.6.
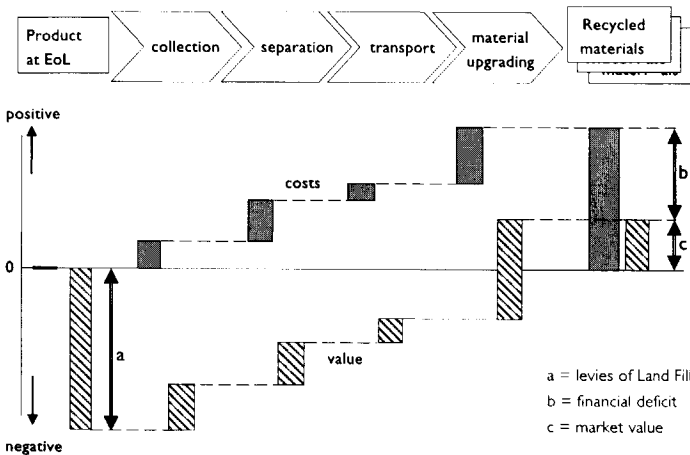
Fig. 4.6: The value and the costs along the recycling chain for non-toxic consumer products.

The negative market value of a product when it is discarded ('a' at Figure 4.6), is
determined by the levy required for Land Fill. In the Netherlands this levy is set at
110 - 160 Euro by the Dutch government for non-toxic materials. It is the right gov-
ernmental policy that this levy has been set slightly higher than the prevention costs -
the eco-costs - of Land Fill (100 Euro per 1000 kg for non-toxic materials, see
Chapter 4.1)[16]: in most cases prevention is more attractive than Land Fill from the
economic point of view.

Each step (activity) in the recycling chain adds value as well as costs. At the end of
the recycling chain, we expect a positive market value of the recycled materials ('c' at
Figure 4.6). The costs of recycling, however, are often higher than the market value of

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[16] For toxic products Land Fill is forbidden in The Netherlands: proper treatment of such waste is obligatory.

the recycled materials (this applies to most of the consumer products; waste paper is one of the exceptions). The deficit ('b' in Figure 4.6) at the end of the recycling chain has to be less than the levy 'a' at the beginning of recycling chain (otherwise there is no economic feasibility for recycling). This deficit 'b' has to be paid in one way or the other, to make the business of recycling profitable. There are 4 major forms of additional payments to the recycling chain:

1. The deficit of the recycling is compensated for by a 'waste treatment levy' ('verwijderingsbijdrage') which is paid by the consumer at the moment of purchase of the product; a list of levies for The Netherlands is given in Table 4.1.
2. The deficit of the recycling is paid from other sources in the 'bundle of costs and benefits'. (An example is given in Chapter 4.2: the reason for demolishing a house is often the fact that the value of the ground area is more than the value of the house; the EoL activities are then a co-product of another activity: project development. See also the example in Chapter 4.6).
3. The deficit is paid by the industry involved in the production and trade of the product type (e.g. glass bottles in The Netherlands).
4. Subsidies from governments.

4.5.2 The EVR model for more advanced sustainable EoL solutions

In the previous chapters the EVR model has been described for waste treatment and recycling systems, systems 4 through 10 of the "Delft Order of Preferences", see Figure 4.5. In this chapter we will deal with:

1. extension of the product life (choice of materials, construction type, maintenance systems, etc.)
2. object renovation (e.g. refurbishing of buildings, renovation of buildings, using former building structures and/or foundations)
3. re-use of components (e.g. repair of cars with components of discarded cars)

The essence of these EoL systems is that the life of a product and/or the life of a product component is extended in time. In practice all kinds of combinations of these 3 systems occur in complex products like office buildings, manufacturing plants, trucks, cars, etc. Therefore the 'cascade' approach (see Chapter 4.1.2 and 3) is not suitable to tackle the problem of analysing these types of systems.

The way the extended life solutions are dealt with in the EVR model, is similar to the approach which is used for eco-costs of depreciation of production facilities as described in Section 3, and is explained hereafter. When, for example, the lifetime of a product is extended by 10%, the eco-costs per year are decreased by 10%. If this enhancement of the lifetime is achieved at the same costs and the same value per year, the EVR is decreased by 10%

The underlying assumption is that eco-costs are distributed in a linear way over the lifetime of a product, similar to the depreciation of the costs of a product. This underlying assumption is also used in Table 4.2, which provides an overview of the eco-costs of an office building. In this table the lifetime of the elements of an office build-

ing is used to calculate the eco-costs per m^2 per annum for each element, in order to determine the eco-costs per m^2 per annum of the total. Note that the subsystems in Table 4.2 (building structure, building systems, interior, computer systems) each have different lifetimes.

It is advised to approach the analyses of extended life solutions (with several subsystems) by calculating the 'eco-costs per annum', applying the following equations:

[4.7] $(eco\text{-}costs\ per\ annum)_{subsystem} = \left(\dfrac{eco\text{-}costs}{lifetime}\right)_{subsystem}$

and,

[4.7] $(depreciation\ per\ annum)_{subsystem} = \left(\dfrac{value}{lifetime}\right)_{subsystem}$

Combining [4.7] and [4.8] results in:

[4.9] $(eco\text{-}costs\ per\ annum)_{subsystem} = (depreciation\ per\ annum)_{subsystem} * EVR_{subsystem}$

For the total extended life system:

[4.10] $(eco\text{-}costs\ per\ annum) = \sum \{ (depreciation\ per\ annum)_{subsystem} * EVR_{subsystem} \}$

The meaning of equation [4.10] is that the eco-costs per annum can be derived from the normal costs of depreciation by multiplying it with the EVR of that subsystem. An example of such a type of calculation is given in Table 4.2, for the same office building as given in Table 3.4. One may argue that equation [4.10] may also be used in situations where the depreciation is not linear, but follows the real market value of a subsystem.

4.6 Example: a warehouse building

As an example of the EoL and recycling in the EVR model, the concrete floor slab and the steel superstructure (including roof, cladding and warehouse racks) have been analysed for EoL and recycling solutions. The summary of this analysis is given in Table 4.3. The warehouse is the same warehouse as given in Table 3.6 and 3.7, and can be summarized with the following characteristics:
-   function: 920 pallet places (900 m^2, outside height 10 m)
-   concrete floor slab: 551,200 kg, eco-costs 99,459 Euro
-   steel, total: 73,000 kg, eco-costs 84,568 Euro
-   total eco-costs of the warehouse, excluding EoL: 257,481 Euro.

The maximum eco-costs of EoL, e_0, have been calculated under the assumption that all materials are dumped in a Land Fill. The minimum eco-costs of EoL, e_{95}, have been calculated for 95% recycling, so only 5% of the total weight ends up in Land Fill.

The net eco-benefit of recycling, allocated to the 'old building' equals: e_0 - e_{95}.

The 'avoided eco-costs of materials' in this case totally depends on:
- the function of the new building which will replace the old building
- the decision of the architect on the possibilities to re-use parts of the old floor slab and to apply recycled materials.

Hence the 'avoided eco-costs of materials', being the net eco-benefit of materials, are allocated to the new building. Suppose the new building has exactly the same function (a warehouse) and the architect applies recycled steel for 95% of the steel elements, and uses the old floor slab. For this case the following data has been calculated, and provided in Table 4.3:
- the eco-costs without recycling and re-use
- the eco-costs of 95% recycling and re-use
- the net eco-benefit of materials.

Note that, when the design load on the floor slab of the new building is less, the thickness of the floor slab can be less, with consequently a lower amount of concrete required and therefore less net benefit of eco-costs.

In the case that the floor slab has to be demolished and removed, the value and the costs along the recycling chain can be analysed, see Figure 4.6. Suppose:
- the negative value (the levy) of Land Fill is 110 Euro
- the costs of crushing and grinding of the floor slab (including extra transport) is 90 Euro
- the value of the granulated material is 10 Euro.

In this case recycling is economically feasible, since the recycling operation results in an added value of 120 Euro at added costs of 90 Euro. In Figure 4.6 the size of 'b' is less than 'a'. The fact that the value of granulate is less than the costs of the granulate is not ruling the economic decision: this deficit is paid from other sources in the 'bundle of costs and benefits' of the total project.
However, when the size of 'b' is more than the size of 'a', the recycling operation as such has less added value than added costs, and will therefore not happen in a free market economy. When society insists on recycling in such cases, governmental regulations, levy systems or subsidies are required to make recycling happen.

4.7 Discussion

Although the methodology for recycling and EoL has been developed within the framework of the EVR model, the same methodology can be used in other systems, like the eco-indicator 95 and 99. This is because of the fact that eco-costs, costs and value are strictly separated from each other. Computer models which are used in the design stage of products, like Simapro and Ecoscan, are structured according to similar principles, which is in line with the way of reasoning of BUWAL (providing LCA

data on virgin metals and 'secondary metals').

Confusion on the analyses of recycling systems stem from the fact that different parameters in the system are often mixed up:
a) eco-costs of recycling activities(Equation [4.5])
b) eco-benefit of recycling (Equation [4.6])
c) costs of recycling activities
d) value of recycling activities
e) value of the recycled materials.

Note that the EVR calculations as described in Chapter 4.5 are only allowed for the parameter a), c) and d) of the aforementioned list, and not for parameter b) nor e). Note also that 'value' is here the market price.

With regard to the enhancement of the durability of products (Equation [4.10]) it is important to realise that the lifetime of *all* subsystems of a product has preferably to be the same, when it is not possible to split the product in subsystems at the End of Life. Subsystems with a longer lifetime than the other subsystems suffer from 'waste of quality'. However, one has to realise that the End of Life of a product is not a matter of the technical lifetime only, it is also related to value aspects of the product. A product can become obsolete for the user for many reasons (van Nes et al., 1998):
1. technical: the product is worn out and no longer functioning properly
2. economic: new products have a lower level of 'Costs of Ownership' (maintenance, energy, etc.)
3. ecological: new products have less harmful impact in the use phase (maintenance, energy, etc.)
4. esthetical: new products have a nicer look, a more fashionable design, a better image ('feel good factor')
5. functional: new products fulfil more functions or fulfil functions better
6. psychological: old products have a negative emotional factor (unpleasant history), new products have a positive emotional factor (gift, pleasant history), 'feel good factor'.

To cope with the obsolescence of point 2 through 5, the product design has to be modular. An obsolete module can easily be replaced then by a new one, instead of replacing the whole product. This principle applies also to the design of buildings.

The fact that a product (or its subsystem) can become obsolete before the product is worn out and no longer functioning properly, is the reason that one should take the 'economic lifetime' as lifetime in the LCA calculations (Equation[4.7]), instead of the 'technical lifetime'.
This is the reason why the depreciation of the eco-costs in the EVR model is done in parallel with the economic depreciation (Equations [4.7], [4.8] and [4.9]).

5. The EVR model as a tool to optimize a product design and to resolve strategic dilemmas

The advantage of combined analysis of eco-costs and value

Abstract

This Section deals with research task 5: define consequences of the new model for 'eco-efficiency' for design and business strategies, check with cases

Product designs for the future combine a high value/costs ratio and a high eco-efficiency. In Section 3, two concepts have been introduced:
- the eco-costs as an LCA-based single indicator for environmental impact
- the 'EVR' (Eco-costs/Value Ratio) as an indicator for eco-efficiency, and as a tool for economic allocation in LCAs.

In this Section, it is shown how the EVR model can support decision taking processes. The following subjects are dealt with:
- the optimization of a product in the design stage by means of the EVR model (the "EV Wheel")
- the optimization strategies for the production+distribution chain of a product (Case: a TV)
- the strategic dilemmas with regard to marketing, pricing and subsidising of products with low environmental impact (Case: a 'low energy TV')
- an investments policy for systems which lower the environmental impact, analysed by means of the concept of the 'eco-payout time'
- the EVR model applied to consumer spending: the buying pattern of consumers, and the so called 'rebound effect'.

5.1 Introduction: the EVR as an indicator for 'de-linking'

In Section 3, the eco-cost has been introduced as a single indicator for sustainability, and the EVR model has been presented for economic allocation in LCAs of product-service systems. The EVR, however, is more than just a multiplier for economic allocation in LCA calculations. In a broader sense it is also an indicator which describes the

level of 'de-linking' of a product-service system, or a part of it. A high level of pros-
perity can only be combined with a low level of pollution and material depletion,
when products (and services) are used with a low EVR. In terms of EVR, the 3 stake-
holders of a sustainable society have each their specific roles:
- the industry has to develop products and services with a low EVR[17]
- the consumers/citizens should have a life style with preferences for products and
  services with a low EVR (e.g. they should spend their money on other activities
  than travelling by air)
- the governments should encourage products, processes and life styles with a low
  EVR (e.g. labour intensive activities) and should restrict products, processes and
  life styles with a high EVR (e.g. energy intensive activities, activities with high toxic
  emissions).

But what does it mean for the decisions the stakeholders have to make? How do
they know they make the right choice in terms of sustainability?

5.2 The EV Wheel (a quantified LiDS wheel) for product design

In the United Nations Publication Paper "*Ecodesign – A promising approach to sustain-
able production and consumption*", (Brezet, Van Hemel, 1997), the LiDS wheel is pro-
posed as a tool to define the design strategy for sustainable products. This LiDS
wheel is a qualitative tool, and at the Delft University of Technology many attempts
have been made to make it quantitative. The EVR model provides the opportunity to
do so. Since the concept of the wheel has been adapted slightly to incorporate the
main aspects of the quality of a product-service system, a new name has been chosen:
the Eco-costs & Value Wheel, in short the EV Wheel.

The EV Wheel is depicted in Figure 5.1 and will be explained hereafter.

The EV Wheel is meant to provide a quantitative overview of the eco-efficiency of
properties of a product, a service or a combination of both (a product-service sys-
tem). A sustainable design is characterized by high scores at the value side and low
scores at the eco-costs side.

The value side of the EV Wheel is based on the '8 dimensions of quality' of Garvin.
Definitions and examples of these 8 dimensions are directly quoted (Garvin, 1988):
1. *Performance* or the primary operating characteristics of a product or service.
    Example: for a car: it is speed and acceleration; for a restaurant: it is good food.
2. *Features* or the secondary characteristics of a product or service.

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[17] In 1995, the World Business Council for Sustainable Development (www.wbcsd.ch/eurint/eeei.htm)
described the role for industry in their definition of eco-efficiency as:
"the delivery of competitively priced goods and services that satisfy human needs and bring quality of life
while progressively reducing ecological impacts and resource intensity, throughout the life cycle, to a level at
least in line with the earth's estimated carrying capacity."
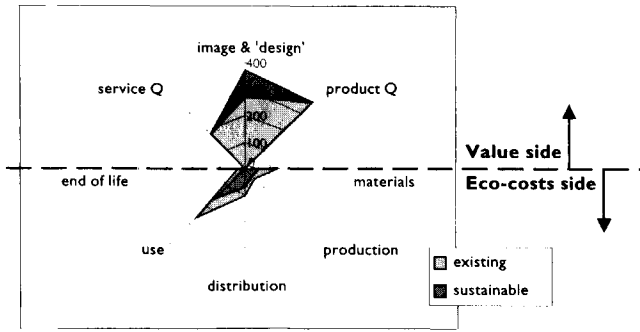
Fig. 5.1: The Eco-costs & Value Wheel (EV Wheel), with value and eco-costs in Euro.

Example: for a restaurant: it is linen tablecloths and napkins.

3. *Conformance* or the match with specifications or pre-established standards.
   Example: for a part: it is whether this part is the right size; for a restaurant: it is whether the meat is cooked according to your request (e.g. "medium, rare").

4. *Durability* or product life.
   Example: for a light bulb: it is how long it works before the filament burns out.

5. *Reliability* or the frequency with which a product or service fails.
   Example: for a car: it is how often it needs repair; for an airline: it is how often flights depart on schedule.

6. *Serviceability* or the speed, courtesy and competence of repair.
   Example: for a car: it is how quickly and easily it can be repaired; for a mail order house: it is the speed and the courtesy with which an overcharge is corrected.

7. *Appearance / aesthetics* or fits and finishes.
   Example: for a product or service: it is its look, feel, sound, taste or smell.

8. *Image* or reputation.
   Example: for a product or service: it is the positive or negative feelings people attach to any new offerings, based on their past experiences with the company. (Note: Garvin mentions here also "perceived quality", however, this expression has been used later on in literature for the total value column).

Based on other management literature, we split the 'serviceability' into two elements:
a) the 'pure serviceability' as the 'design for maintenance' of the product and/or the processes in a service organization
b) the aspect of customer care (even called 'customer intimacy'), e.g. communication, competence, consistency, flexibility, integrity, reliability, speed, value and image.

For the purpose of the EV Wheel, we group the 8 dimensions as follows in 3 aspects of value:
i. the 'product quality' being the following 4 'core quality' dimensions: 1. Performance; 3. Conformance; 4. Durability; 5. Reliability;
ii the 'service quality' being the following 3 'extra' dimensions: 2. Features; 6a. Serviceability; 6b. Customer Care;
iii. the 'image' being: 7. Aesthetics and 8. Image.

These 3 aspects of value can be determined in terms of money (the 'fair price'[18]), where

[5.1] *(total value) = ('fair price' of the 'product quality') + ('fair price' of the 'service*

quality') + ('fair price' of the 'image')

The value side of Figure 5.1 depicts the 'fair price' for each aspect in Euro. The sum of the three fair prices in the EV Wheel equals the total value of the product-service system for the total life cycle.

The eco-costs side of Figure 5.1 depicts the eco-costs (in Euro) of the product-service system for the following aspects of the Life Cycle Chain:
- materials
- production
- distribution
- use
- end of life.

Note that the sum of these eco-costs equals the total eco-costs product-service system for the total life cycle. The EV Wheel is basically a communication tool: it shows in one picture the advantages (and disadvantages) of a specific design in comparison with other designs[19]. The EVR of a total product-service system is the sum of the eco-costs of the five aspects (the lower part of the wheel) divided by the sum of the fair prices (the upper part of the wheel).

Note: The 'existing' and the 'sustainable' design data in the EV Wheel of Figure 5.2 correspond with the data of two design cases of a 28" television, '6 hours watching per day', similar to the cases which are described in Chapter 5.4 (Table 5.3) hereafter.

5.3 Design strategies in the business chain of a product, case: a television

How to optimize a production+distribution chain by means of the EVR model, is dealt with in this chapter. The approach will be explained by a simple example of a 'standard' television with a 28" CRT (data is given for a typical configuration, slightly rounded off, for confidentiality reasons). See Table 5.1 and Table 5.2.

Table 5.2 shows that:
- the eco-costs of the components are approximately equal to the eco-costs caused by the assembly, distribution, advertising and retail of the television set. Therefore,

[18] *From the consumers point of view a 'fair price' for each of the value aspects can be determined (Gale, 1990), see Annex 5b and 5c*

[19] *The upper part of the wheel shows if and in which aspects a product-service system is attractive to customers. The lower part shows if and in which aspects the product has a low ecological burden for our earth. A sustainable product combines a big shaded area in the upper part and a small shaded area in the lower part. The wheel makes it clear on where to focus to improve the design.*

it is not sufficient to analyse a product by the materials and the primary processes only (note that the eco-costs for 'Use phase' and 'End of Life' will be dealt with later in Chapter 5.4 and Table 5.3).

- the EVR gets lower towards the end of the production and distribution chain. This is because of the higher labour content of service and image, which is added to the product at the end of the production and distribution chain.

Figure 5.2 depicts the development of the value and the eco-costs in the production+distribution chain. From Figure 5.2 it is clear that the distribution step requires extra attention from the environmental point of view: the increase of the costs (value) is low, but the increase of the eco-costs is relatively high.
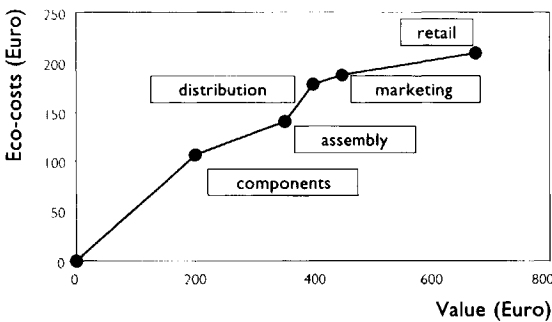
Fig. 5.2: The value and the eco-costs cumulative along the production and distribution chain (data for a 28" television, see Table 5.1 and Table 5.2).

The two dimensional approach of the Eco-costs / Value Ratio seems to be crucial in calculating as well as understanding the elements of the eco-efficiency of a product, a service or a combination of both (a product-service system). It reveals the fundamental differences between environmental strategies in each step of the chain (these fundamental differences are explained further in relation to the 'rebound effect' [20], Chapter 5.6):

- improvement of production processes (lowering the eco-costs at *constant* cost level)
- environmental material selection (lowering the eco-costs at often *higher* cost levels)
- "savings" in e.g. transport (lowering both costs *and* eco-costs)
- improvement of the perceived value (*enhancing the value* without adding considerable extra eco-costs).

[20] The combined, two dimensional, approach of the eco-costs and the EVR reveals information on the 'rebound effect' (Chapter 5.6): when the eco-costs of a product is lower, but the EVR of the cost structure stays the same, less eco-costs goes hand in hand with less costs, and therefore will translate in less price in the market. The consumer will then spend the extra money on other products, so it becomes questionable whether sustainability is supported. To support a sustainable society, a low EVR is required rather than low eco-costs only.

Only a good understanding of value, costs and eco-costs along the total chain can lead to the required improvements in design (Design for Sustainability). With regard to the strategic level of product portfolio management, it is essential to understand the chain (also called 'the pool' of business activities[21] of a product-service system), in order to manoeuvre a corporation into a position which is suitable for a sustainable future. A low EVR indicates that the product is fit for use in a future sustainable society. A high EVR indicates that the value/costs ratio of a product might become less than one in future (since 'external' costs will become part of the 'internal' cost-structure), so there is no market for such a product in future.

Since the success of a product-service system in the market depends on the fact whether or not the consumers will buy the product, it is important that consumers can understand the concept of eco-costs. The perceived value is what they feel and think about the product, the cost is what they pay for it, but the concept of eco-costs is new for them. This means that companies face a new challenge in the marketing of eco-costs.

5.4 Dilemmas on strategies for marketing, pricing and subsidising of sustainable products, in the case of a 'low energy' TV

In the previous chapters, the first steps in the chain have been analysed only. In this chapter we will analyse the total chain, especially the aspects of the 'Use phase' of a product.

Equivalent to the Total Costs of Ownership (Life Cycle Costing) approach of financial evaluation, the Total Eco-Costs of Ownership is defined and applied to a 28" television. See Table 5.3 for two cases:
- "the American family" in Europe, watching 6 hours per day on average
- "the European young bachelor", watching 1.5 hours per day on average.
It is assumed that the lifetime of the television is 10 years, and that the energy consumption is 100 W during 'watching' and 2.5 W during 'stand by' (at a renewable electricity price of 19.60 Euro per GJ).

Table 5.1, 5.2 and 5.3 (column 'standard 28" television') show that a 'quantum leap' in eco-costs of the life cycle of a television can never be achieved by replacement of the materials and/or components of the television alone: an integrated design approach is needed for both of the market niches separately (the '6 hour' and the '1.5 hour' cases).

Interesting conclusions can be drawn from Table 5.3 in the following hypothetical situation. Suppose that a new 'low energy' type of television will be launched with the following characteristics
- the price and eco-costs are 15% higher
- the energy consumption is 25% lower (for watching as well as stand by).

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[21] *Referring to the concept of the 'profit pool' of (Gadiesh et al., 1998).*

The first question now is whether this new television is attractive from the environmental point of view. The answer is:
- *yes* when we watch the TV for more than 6 hours per day on average, see 5th column Table 5.3
- *no* when we watch for less than 1.5 hours, since the extra eco-costs in the production chain is more than the savings of eco-costs during the use- phase, see 5th column Table 5.3.

From the governmental point of view it seems to be attractive to stimulate the low energy television by subsidizing (or differentiating in taxation), to influence the purchasing decision of the consumer in the retail shop (remember that the purchase price is 15% higher without subsidy). However, when the low energy television is purchased then by people who watch less than 1.5 hour per day, the government is *subsidizing eco-costs* !
The only solution is to design a separate marketing strategy for each of the separate market niches. In all circumstances the issue has to be clearly communicated to the market (the consumers).

The second question is whether or not the government should stimulate the replacement of old televisions by the new low energy televisions. From governmental point of view this seems to be attractive since it results in less energy consumption.
However, televisions are recycled then at an earlier (premature) stage than is required from the durability point of view. This dilemma can be resolved by calculating the effects of replacement of the old type television (see Table 5.3):
- assuming that the lifetime of a TV is 10 years, the related eco-costs per year of the depreciation of the standard TV is 20.8 Euro per year
- the savings of the eco-costs of energy is 65 Euro over a period of 10 years, so 6.5 Euro per year.

The conclusion is that, from an environmental point of view, it is not reasonable to throw away the old TV when it is still working: the energy savings are not enough to counterbalance the negative effect of throwing away the old TV too soon.

The question whether or not to invest in a system which has a lower environmental impact, is one of the major issues on the road towards sustainability. It is one of the topics where industry and governments should have a well defined strategy. The investment policy with regard to investments in new 'cleaner production' systems is dealt with in the next chapter, as well as investments in general production assets.

5.5 The eco-payout time for investments

It is important for companies and governments to know which investment is the best choice on the road to sustainability. We introduce here the *eco-payout time*, analogue to the pay-out time, as an investment criterion:

$$[5.2] \ eco\text{-}payout \ time = \frac{(eco\text{-}costs \ of \ the \ investment)}{(eco\text{-}costs \ of \ the \ savings)}$$

The meaning of this equation is depicted in Figure 5.3. This Figure shows that only after the pay-out time period, the savings are bigger than the expenditure at the start. So after the pay-out time period we have a positive balance on eco-costs.
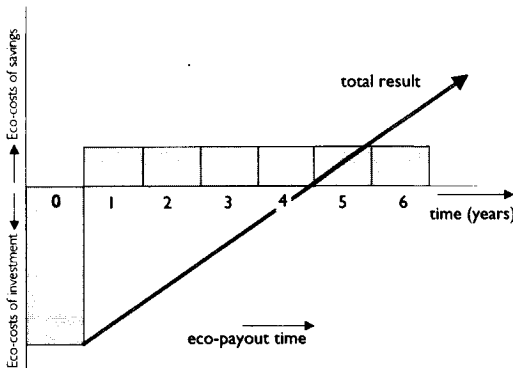
Fig. 5.3: The eco-payout time.

In practice, it would be a big step forward in the direction of sustainability if companies not only base their investment decisions on the pay-out time (or other economic criteria), but would also take the eco-payout time into consideration. In doing so, these companies would improve their position step by step in the competitive world of future sustainability.

Equation [5.2] can be transformed to:

$$[5.3] \ eco\text{-}payout \ time = \frac{[\ (value \ of \ investment) * EVR_{investment} \ ]}{[\ (value \ of \ savings \ per \ year) \times EVR_{savings} \ ]}$$

or:

$$[5.4] \ eco\text{-}payout \ time = (pay\text{-}out \ time) * \left(\frac{EVR_{investment}}{EVR_{savings}} \right)$$

When a company bases the investment decisions on such a double criterion (pay-out time as well as eco-payout time), investments in savings of energy or material will prevail (before, for example, savings in labour) because of the corresponding EVRs.

There are types of investments for cost savings which are normally abandoned *directly*

after the depreciation period (= the pay-out time). In such cases one should be certain that the eco-payout time is shorter than the pay-out time, otherwise a negative balance of eco-costs is left. In these cases one should fulfil the following criterion:

[5.5] $EVR_{investment} \leq EVR_{savings}$

For investments in computer software for instance, this criterion is no problem: labour is replaced by labour. For investments in computer hardware this criterion is a problem: the EVR of a computer is higher than the EVR of the labour it replaces. In this case one should keep the hardware longer than the depreciation period !

In the case of replacement of production facilities (investments without additional savings), the ecological balance is always negative: one should always consider here the alternatives of maintenance and/or renovation. This applies also for offices.

5.6 The EVR model and the buying pattern of consumers.
The rebound effect, case: a car

There is also a consumers side of the de-linking of economy and ecology. Under the assumption that most of the households spend in their life what they earn in their life, the total EVR of the spending of households is the key towards sustainability. Only when this total EVR of the spending gets lower, the eco-costs related to the total spending can be reduced even at a higher level of spending. There are two ways of achieving this:
1. at the product level: the delivery of eco-efficient ('low EVR') products and services by the industry
2. at the consumers level: the change of lifestyle in the direction of 'low EVR' consumption patterns.

At the product level, our society is heading in the right direction: gradually industrial production is achieving higher levels of the value/costs ratio and is at the same time becoming 'cleaner'. At the consumers level, however, our society is suffering from the fact that the consumers preferences are heading in the wrong direction: towards products and services with an unfavourable EVR (like bigger cars, more kilometres, intercontinental flights for holidays). These unfavourable preferences can be concluded from Figure 5.4.

Figure 5.4 shows that people in The Netherlands (and probably in the other EC countries as well) spend relatively more money on cars and holidays when the have more money available. Other studies (Kramer et al., 1998) show that people tend to have intercontinental holidays at the moment they can afford it. Although not enough data is available yet to make an eco-cost calculation on the spending patterns of households, it is obvious that the evolving preferences of the period 1990-2000 will become a big problem in the beginning of the next century, since the EVR of housing is much lower than the EVR of transport and (inter)continental holidays by plane:
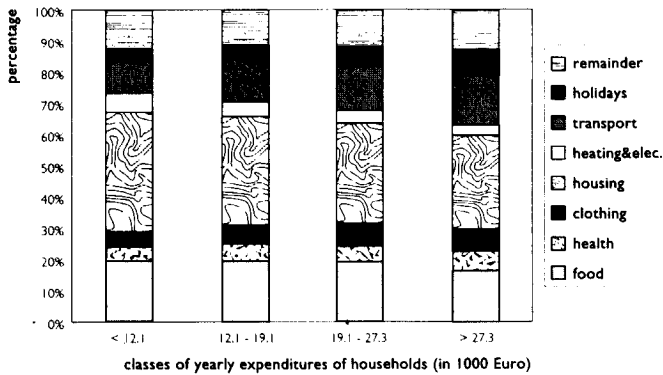
Fig. 5.4: Preferences of spending of households (spending of households in The Netherlands, 1995)
Source CBS, The Hague.

- the EVR of housing is estimated in the range of 0.3-0.4
- the EVR of transport by car in Europe is estimated in the range of 0.8-1.0.
So, when the European households get richer, their spending will gradually go in the direction of a higher EVR, which is the wrong direction in terms of eco-efficiency and sustainability.

The consumer preference is relevant for the design of products and services with respect to the so called 'rebound effect'. See Figure 5.5. When eco-costs are reduced by savings, the economic value (costs for the consumer) is reduced as well, so the consumer will spent the money somewhere else. In the example of product 1 of Figure 5.5, the net result is positive, since the money which is saved, is spend on another product with a lower EVR. In the example of product 2 of Figure 5.5, however, the net result is negative, since the saved money is spent on a product with a higher EVR. The conclusion is that savings are only positive for the environment when savings are achieved in areas with a high EVR.

A typical example of the rebound effect is related to the efficiency increase of light bulbs: when consumers spend the saved energy on more light (e.g. in their gardens) or on electricity for other domestic appliances, it does not help much in terms of sustainability.

In general, however, one may conclude that savings on energy can have a positive effect in terms of sustainability, since the EVR of energy is relatively high (1.5 – 1.8, Chapter 3.3) in comparison with other expenditures. Savings on luxury goods (generally a low EVR because of the high labour content), might be negative since the rebound might be in the area of more energy (in the form of travel).
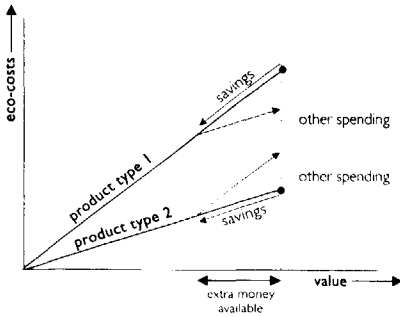
Fig. 5.5: The "rebound effect" of consumer spending.

In product design, savings in energy require higher product costs. An example of such a saving is related to making cars lighter (in order to reduce fuel consumption). Figure 5.6 shows the result of calculations for middle class German cars and for European fuel prices (Saur, 1999).
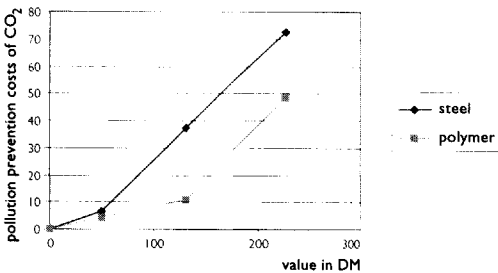
Fig. 5.6: The Total Costs of Ownership and the pollution prevention costs of CO_2 for two alternative designs for a part of the coach-work of a middle class German car.

The left hand side of the two lines relate with the production (the end-of-life phase included) of a specific part of the coach-work of the car. The right hand side of the two lines depicts the effect of the fuel consumption related to that specific part of the coach-work (0.305 litre fuel per 100 km and 100 kg). At a total lifetime of 250,000 km, SMC (a polymer) is break even with steel from the economic point of view, but much better from the environmental point of view. This is an example where there is no rebound effect, since the economic savings on the fuel equal the extra costs of the coach-work.

It is good to mention here that the change in cost structure (from energy costs towards product costs) may have a serious impact on the marketing of the product. When the aforementioned example of coach-work is applied to the total car (a hypothetical case), the price of the car will go up with nearly a factor two-and-half, which may only be marketed via total lease concepts (for the total lifetime of the car!).

5.7 Conclusions

The two dimensional approach of the Eco-costs / Value Ratio seems to be crucial in calculating as well as understanding the elements of the eco-efficiency of a product, a service or a combination of both (a product-service system). It reveals the fundamental differences between:
-   improvement of production processes (lowering the eco-costs at the same value)
-   better materials selection (lowering the eco-costs at often higher costs levels)
-   'savings' in e.g. transport (lowering both costs and eco-costs)
-   improvement of the perceived value (enhancing the value without adding considerable extra costs).

Only a good understanding of value, costs and eco-costs along the total chain can lead to the required improvements in design (Design for Sustainability). On the strategic level of product portfolio management is the understanding of the chain (or 'the pool') essential to manoeuvre a corporation into a position which is fit for a sustainable future. With regard to investments, the eco-payout time should play a role in the decision taking process.

The development of a sustainable society needs a combined approach:
✓ by the industry: the delivery of eco-efficient ('low EVR') products and services
✓ by the consumers: the change of lifestyle in the direction of 'low EVR' consumption patterns.
Governments should stimulate industry and consumers to make the right choices in terms of sustainability.

6. The eco-costs, the costs and the EVR of road transport of consumer goods

Case: An LCA based calculation on transport of fresh fruit and vegetables from a Dutch greenhouse to a German retail shop

Abstract

This Section deals with research task 6: apply the EVR model on one complex service system, being a transport case.

In most of the Life Cycle Analyses of consumer goods, only the direct emissions of road transport are taken into account, applying direct emission data for diesel trucks per tonkilometer. For consumer goods this is far from adequate since, for most of the cases:
- distribution of consumer goods is not determined by weight, but by volume
- distribution of consumer goods is done by quite complex logistic chains (so called hub-and-spoke systems) to minimize transport costs
- often there is a quite complex interaction between product, transport packaging and logistic distribution system
- the indirect emissions (manufacturing and maintenance of trucks, trailers and forklift trucks, as well as construction and maintenance of warehouses and roads) are considerable in comparison with the direct emissions (diesel fuel for trucks).

So the LCA of the transport of consumer goods is quite complex, both in terms of logistics and in terms of the complexity related to the so called 'allocation' of systems (trucks, warehouses, etc.) which are partly used by the goods which are transported.

The complexity of the LCA structure requires the use of a 'single indicator'. In this Section the virtual eco-costs '99 of Section 3 is used as single indicator.
A computer program has been developed to analyse such transport systems, applying the economic allocation principle to build a 'totally integrated LCA'. It is shown how the EVR model can be used to simplify calculations, making calculations feasible without the computer model.

Since there is an ongoing debate on the environmental aspects of re-usable crates versus paper board boxes in The Netherlands since 1990, a calculation is given on the transport of fresh fruit and vegetables from a Dutch greenhouse to a German retail shop. Two

Packaging systems are compared:
- *solid board boxes (made from recycled paper)*
- *re-usable plastic crates (made of High Density Polyethylene, HDPE).*

From a environmental perspective the analyses show that:
- *the solid board systems seems to be better from the environmental point of view*
- *plastic crates for fresh fruit and vegetables should be designed for maximum relative volume content (instead of minimum materials for the crate) to optimize the use of the transport system*
- *an attempt should be made to design the system of solid board boxes for two or three round trips per box for 'short distance & high volume' applications.*

6.1 Introduction

The road transport of products is increasingly becoming an environmental burden, since the volume of road transport is growing at an even faster rate than our economy. Based on macro-economic statistical data, a recent study (Bos, 1998) on the indirect energy requirements and emissions from freight transport has shown that the 'indirect' emissions are important in comparison with the 'direct' emissions. The 'direct' emissions result from the use of energy (diesel fuel), the 'indirect' emissions are resulting from:
- manufacturing and maintenance of trucks
- construction and maintenance of warehouse buildings
- construction and maintenance of road infrastructure.

In the Life Cycle Analysis (LCA) of a product, transport is obviously an element. However, the emissions of road transport of consumer products cannot be derived from the aforementioned study, since each specific type of consumer product has its own specific type of logistic transport and distribution system where storage and utilization rates of trucks play an important role. Furthermore, the transport costs and emissions for consumer products are in nearly all cases based on volume and not on weight, whereas macro-economic data are based on weight. So it was decided to make an LCA based analyses of the transport function, where the transport packaging system is an integral part of the logistic distribution system.

In The Netherlands as well as in other EC countries, there is, since 1990, an ongoing debate on the environmental aspects of re-usable plastic crates versus solid and corrugated board boxes. Is a solid or corrugated board box better than a plastic crate, since the boxes are made of recycled material (recycled paper) or is a plastic crate better since it is re-usable (durable)? How about the transport and handling of the empty crates? How about the fact that a crate has a poor net volume versus gross volume? How about the pollution of mills for board and recycled paper?
It is generally accepted that retail companies have lower distribution costs when they apply crate systems, but it is also known that crate systems tend to be expensive at the front end of the chain (filling, storage and transport). Does the environmental burden go hand in hand with the costs? Within what distance is the crate more

attractive from the environmental perspective? And what are the key elements to improve the design of both packaging systems?

Since the transport of fresh fruit and vegetables from the Dutch greenhouses is done in re-usable plastic crates as well as in solid (and corrugated) board boxes, this is used as a case in the study. Germany was selected as consumers market, giving an interesting range of transport distances: Duisburg (Rhurgebied), 200 km; Frankfurt, 500 km; München, 800 km.

Because of the complexity of the logistic system, there is a need to express the results of the several classes of the underlying LCAs in one parameter: a so-called single indicator. We will apply here the eco-costs of Section 3. This choice also enables the use of the EVRs as allocation parameters in the LCA model (according to ISO 14041, see Section 3).

In the following, first the overall logistic system is described, and then the details of a link in the chain. Thereafter the calculation structure of costs and eco-costs are given, and the results of calculations are discussed in terms of design consequences. A method is provided to make a quick estimate of the eco-costs of complex logistic systems.

6.2 The transport chain: a hub-and-spokes system

The transport and distribution chain for Dutch fresh fruit and vegetables is a so called 'hub-and-spokes' system:
- in the first leg the goods are transported from the greenhouse to the warehouse of the auction or export company in Holland (Hub 1), where all fruit and/or vegetables of that day are stored
- in the second leg the goods are transported to the distribution centre of the retailer in Germany
- in the third leg the goods are distributed from the distribution centre (Hub 2) to the retail shops.
This system is depicted in Figure 6.1.

Figure 6.1 also shows the how the crates (and pallets) are returned in the chain. Within the EC, packaging materials have to be returned to the source, so the waste paper (and board) of boxes are returned as well. This might be done via the chain or separately in waste paper chains. Storage and cleansing of the crates is done at the warehouses of the auctions (extra transport of crates between auctions is only done when the request for empty crates is out of balance with the supply).

Such an hub-and-spokes system is also common for goods other than fresh food. The logistic idea behind it is that in such a system the truckload for the long distance (in this case Holland-Germany) can be maximized. ("hub-and-spokes" refers to a wheel: freight is collected - the "spokes" - and temporarily stored in a warehouse - the
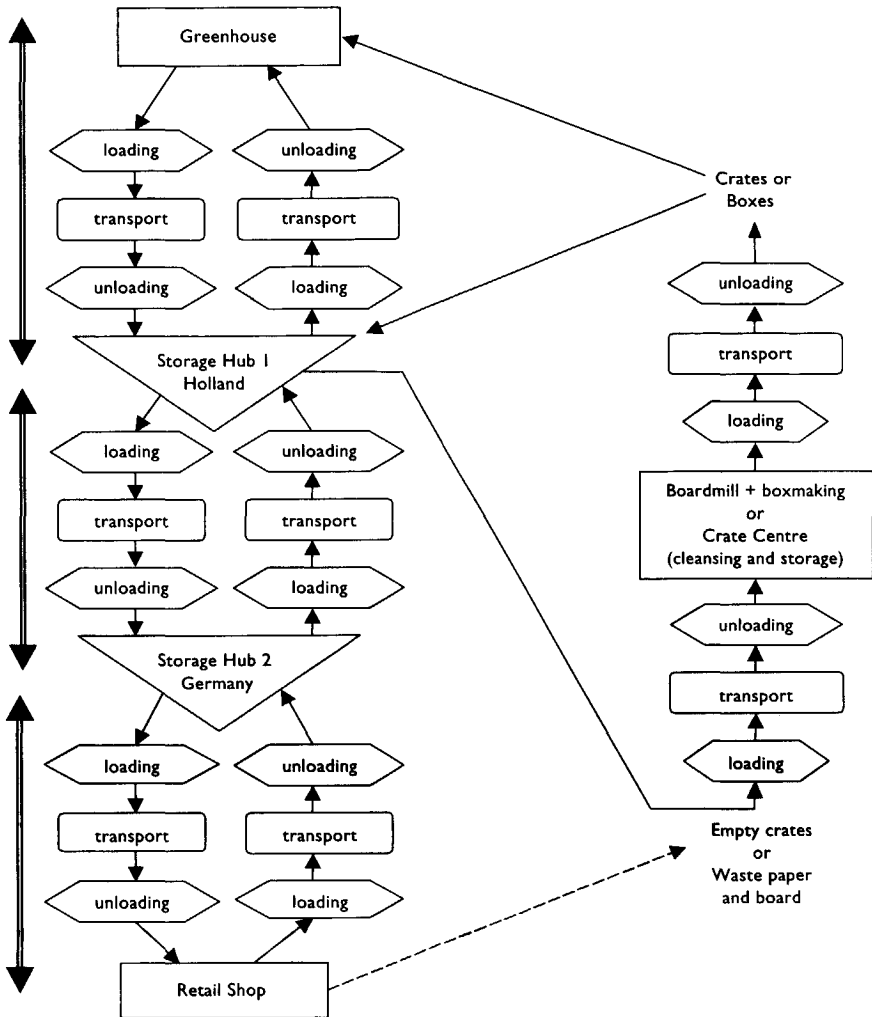
Fig. 6.1: Structure of the transport and distribution system.

"hub" -, transported at a high frequency and optimum efficiency to the other hub, stored, and distributed there over the adjacent area - the "spokes" -).

Most of the international transport companies operate in this way to minimize costs. They run their own warehouses in the hubs: in a well designed logistic system the extra costs of intermediate storage is less than the savings of having a better utilization of the total truck fleet. Since the EVR of transport is higher than the EVR of storage and its related handling, optimization of costs go here hand in hand with minimization of environmental burden (see Chapter 6.6).

There are many hubs (auctions and export companies) in Holland and many in Germany (every Retail Company has its own distribution centres). The trucks from

Holland to Germany are basically operating as shuttles: the trip back to Holland is either filled with empty crates or, in the case of "one way" transport packaging, the transport companies try to transport other commercial goods on the trip back to Holland. However, in such a fast and frequent operation it is hardly feasible to arrange 100% payload for the trip back. So the economic feasibility of re-usable crate systems depends on the distance for transport and the availability of other commercial freight for the trip back.

6.3 The structure of one link (leg) in the chain

In order to analyse the logistic system, the structure of one link (leg) in the chain has to be detailed on the level of activities:
1. pallets with full crates have to be transported from the storage or filling area to the dispatch area by forklift trucks
2. pallets have to be loaded by forklift trucks
3. the truck is driving from place A to place B
4. pallets are unloaded by forklift trucks
5. pallets with empty crates are loaded with forklift trucks
6. the truck is driving from place B to place A
7. pallets with empty crates are unloaded with forklift trucks
8. pallets with empty crates are transported to storage.

This process is depicted in Figure 6.2.
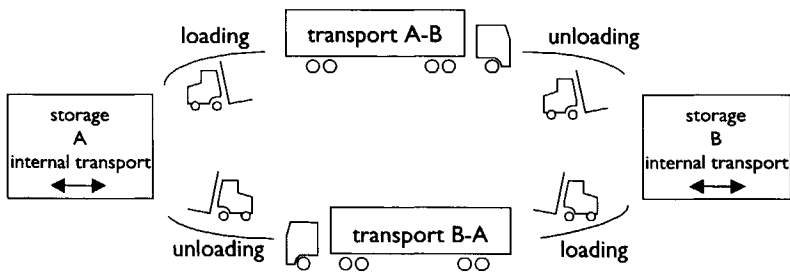
Fig. 6.2: The structure of one link (leg) in the chain.

So there are three main activity groups:
I. transport
II. loading and unloading
III. storage.

Note: From Chapter 6.2 it can be concluded that storage A and storage B of the transport cycle of Figure 6.2 might change each cycle. There are many "storage A" locations in the front end of the chain (there are many greenhouses in Holland) and many "storage B" locations in the rear end of the chain (many distribution centres in

Germany). Since this complexity does not influence the calculations, it is left out in the following analyses.

The main elements of this link of the chain are:
A. the truck
B. the forklift truck
C. the warehouse for storage
D. the road infrastructure.

Each of these elements comprises (the so called "attributes"):
- the object
- the 'direct' energy requirements (i.e. fuel, electricity)
- the related 'direct' labour (e.g. the forklift truck driver)
- indirect costs like insurance, interest, etc.

Each object has its own life cycle ('value chain'):
- the materials required
- the manufacturing
- the distribution (of the truck and the forklift truck)
- the use and the maintenance
- the end-of-life.

According to this structure, a spreadsheet program has been made to facilitate the calculations. In the input of the spreadsheet program, the activity is defined per "main element", the output gives the costs and the eco-costs of the sum of all activities. In the Chapter 6.4 the general data on the costs and the eco-costs for each main element are summarized. In Chapter 6.5 it is shown how the costs and the eco-costs of activities in the transport cycle and in the transport chain are calculated from the general data of the main elements.

6.4 General data on the main elements

6.4.1 Truck+trailer, Lorry, and Van
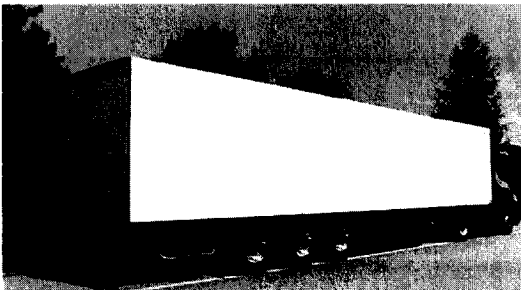
Fig. 6.3: A truck + trailer as normally used in the EC for transport of fresh food.

The type of truck+trailer which has been analysed in this study is depicted in Figure 6.3

The costs per kilometre (EVO, 1999) (Kuipers, 1998) are calculated in Table 6.1:
- truck+trailer (net 24 tons, 26 pallets)   0.525 Euro/km
- lorry (net 5 tons, 10 pallets)   0.334 Euro/km
- van (net 5 m^2, 2 pallets)   0.195 Euro/km[22]

The costs of the driver is about 18 Euro/hour (Kuipers, 1998). This is based on approx. 2000 driving hours per annum (by Dutch law there is a maximum of 110 driving hours per 2 weeks).

The eco-costs of trucks, lorries and vans are calculated according to the scheme of Figure 6.4 where:

total eco-costs for each step in the chain = (pollution prevention costs of emissions) + (eco-costs of materials depletion) + (eco-costs of use of energy) + (eco-costs of labour)
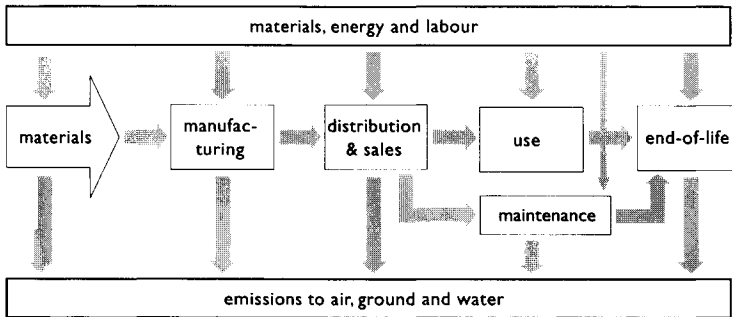
Fig. 6.4: The LCA calculation structure.

The results of the calculations are given in Table 6.2. through 6.11.

The eco-costs can be summarized as (see Table 6.2):
- truck+trailer (net 24 tons, 26 pallets)   0.414 Euro/km
- lorry (net 5 tons, 10 pallets)   0.267 Euro/km
- van (net 5 m^2, 2 pallets)   0.173 Euro/km

The table above is excluding eco-costs of the driver. The cost of the driver is about 18 Euro/hour (Kuipers, 1998). This is based on approx. 2000 driving hours per annum (by Dutch law there is a maximum of 110 driving hours per 2 weeks). The EVR is in

[22] It has to be mentioned here that the calculations have been done on the basis of a diesel fuel price of 0.66 Euro per litre incl. VAT, being the price level of mid 1998 in The Netherlands. The price level January 2001 was approximately 25% higher, resulting is an increase of approximately 9% of the costs of a truck, lorry or van per km.

this case estimated at 0.05 , so the eco-costs of the driver is estimated at 0.9 Euro/hour (methodology as given in Section 3).

6.4.2 Forklift truck

General financial data on forklift trucks are provided in Table 6.12. The costs of a forklift truck is 6.26 Euro/hour (Brantjes, 1999) (Caterpillar, 1999). The eco-costs of forklift trucks are 6.66 Euro/hour. The calculation is summarized in Table 4.13. Details are given in Table 6.14 through 6.16. The costs of the driver is about 16 Euro/hour. The EVR is in this case estimated at 0.05 , so the eco-costs of the driver is estimated at 0.8 Euro/hour (methodology as given in Section 3).
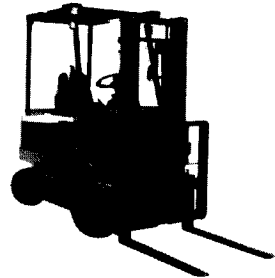
6.4.3 Warehouse

General financial data on a warehouse of 920 pallets (conventional storage in racks, 4 high) are provided in Table 6.17. The costs of storage are:
- unconditioned   44.6 Euro/ pallet.year
- conditioned   83.6 Euro/ pallet.year

The eco-costs have been calculated in Table 6.18 (details are given in Table 6.19, 6.20 and 6.21):
- unconditioned   15.3 Euro/ pallet.year
- conditioned   47.8 Euro/ pallet.year

6.4.4 Road infrastructure

The 'embodied energy' of road infrastructure in The Netherlands has been studied at IVEM of the university of Groningen (Bos, 1998). This study has been based on the following macro-economic data for the year 1990 in The Netherlands:
1. total vehicle "distance x load" by trucks: 47.12 109   tonkm/yr
2. load factor of utilization of the total truck fleet for "long distance"   0.5
3. total embodied energy in road infra. (incl. maintenance)[23]:   888   PJ
4. depreciation of (3.) over 50 years   17.8   PJ/year

The above data result in an embedded energy in road infrastructure of:
                                                                   0.38   MJ/tonkm

[23] *The total embedded energy in roads in The Netherlands is estimated at 3471 PJ, of which 888 PJ has been allocated to trucks (Bos, 1998).*

Since the majority of the 'embodied energy' stems from the energy used by road transport during the construction phase, and since the major part of that is the use of diesel, the 'embodied energy' is directly converted to eco-costs by the price for sustainable energy for diesel: 28.70 Euro/GJ (See Table 3.2). So the eco-costs of road infrastructure[24] can be estimated as:

'maximum load' ∗ *'load factor'* ∗ *'embedded energy in roads'* ∗ *'eco-costs of sustainable energy'*

Which results in the following data of eco-costs of road infrastructure for a truck + trailer: 24 (ton) x 0.5 x 0.38 (MJ/tonkm) x 0.0287 (Euro/MJ) = 0.13 (Euro/km)

The above allocation methodology can neither be applied to vans nor to lorries. The main reason is that the above methodology is based on macro-economic long distance transport data. Vans are for short distance distribution only, where "tonkm" data do not apply. It seems to be reasonable to develop an allocation methodology for vans as part of a methodology for passenger cars. This was, however, beyond the scope of this study. In line with the general purpose and the general philosophy of the calculation method of this study however, the allocation of the "eco-costs of road infrastructure" to lorries and vans has been based on the maximum number of pallets which can be carried (an arbitrary, but logical choice):
- lorries   0.05 (Euro/km)
- vans   0.01 (Euro/km)

6.5 Activity Based Costing calculation for costs and eco-costs of a total transport cycle

A computer spreadsheet program has been developed to calculate the costs and eco-costs of transport, based on the data of the previous chapter and based on the following input per transport leg for the transport, the loading and the unloading, and for the storage respectively:
- type of vehicle (truck+trailer, light lorry, van)
- number of pallets in the vehicle
- number of pallets return
- percentage of freight in vehicle (other freight might be transported at the same time)
- percentage of freight in vehicle return (when there is no other return freight 100%)
- distance in km
- waiting time for vehicle at docks for loading and unloading
- loading and unloading time per pallet for forklift truck

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[24] Note that the eco-costs of the embodied energy is the major part of the total eco-costs of infrastructure. A quick estimate shows that the total eco-costs might only be 20% higher. A detailed LCA analysis is recommended.

- time for forklift truck for storage in the warehouse (per pallet)
- type of storage (conditioned or unconditioned)
- storage time of pallets.

The above set of input data enables an "Activity Based Costing" calculation for the costs as well as the eco-costs (see the first paragraph of Chapter 6.3 and see Figure 6.2).

Such a calculation has been made for transport of tomatoes and peppers from the Dutch greenhouses to the retailer shops in Germany (Duisburg, Frankfurt and München). The main characteristics are:

- for the first transport leg: truck+trailer, distance 50 km at a speed of 30 km/hour, number of pallets 26 (full truck load), storage 1 day at the greenhouse
- for the second transport leg: truck+trailer, distance 200 km, 500 km and 800 km at a speed of 70 km/hour, number of pallets 26 (full truck load) , storage 1 day at the German distribution centre
- for the third transport leg: truck+trailer, distance 50 km at a speed of 30 km/hour, average number of pallets 21 (80% truck load)[25], storage 1 day at the distribution centre of the retailer.

The calculations have been made for two types of transport packaging:

- plastic re-usable crates
- solid board boxes ("trays").

General data on solid board boxes and plastic re-usable crates are provided in Annex 6 summarized in Table 6.22 For re-usable crates the following data has been applied:

- content per pallet   2279 (litres)
- costs of transport packaging per pallet   11.00 (Euro)
- eco-costs of transport packaging per pallet   6.05 (Euro)

For solid board boxes ("trays") the following data has been applied:

- content per pallet   2467 litres
- costs of transport packaging per pallet   49.50 (Euro)
- eco-costs of transport packaging per pallet   7.26 (Euro)

The reason that the content ("net transport volume") per pallet of re-usable crate is lower than the content of board boxes, is because of the wall thickness of the crates. The difference with solid board boxes is about 8.3 %. This means that transport by solid board boxes is 8.3% more efficient by volume. Although the total eco-costs per *pallet* for the crates (based on approx. 30 round trips) is about 17% lower than the eco-costs of the solid board boxes, the difference *per litre* is only 10%.

Table 6.22 and Annex 6 show that the costs of a re-usable crate system is much lower than the costs of a system with solid board boxes. For this reason, all big retail companies have switched to crate systems for their short distance operations.
In the next chapter, results of the calculations of "the total chain" are presented.

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[25] *for the third leg it is obvious that in reality the truck is loaded with a full range of products and not with peppers or tomatoes alone; for the calculation, however, this does not make any difference.*

6.6 Costs and eco-costs of transport of fresh tomatoes and peppers from Holland to Germany, results from the calculations.

The total transport chain (transport cycle) of the calculation is summarized in Figure 6.5, where the crates are cleaned and stored at the warehouse of the auction. The results of the calculation for plastic crates as well as solid board boxes are depicted in Figure 6.6 under the assumption that there is no other freight available which can be transported in the return leg from Germany to Holland ("leg 2").
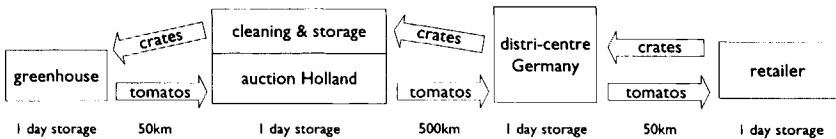
Fig. 6.5: Transport cases of fresh tomatoes and peppers from Holland to Germany.
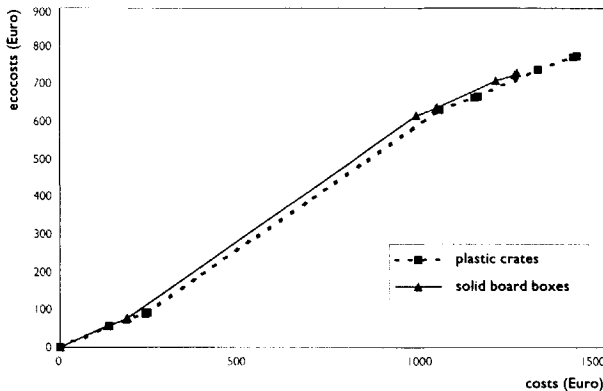
Fig. 6.6: Total costs and eco-costs of transport from Holland to Frankfurt (leg 2 is 500 km), per full truckload (26 pallets), excluding packaging. Note: The assumption is that no other return freight is transported in leg 2.

It can be concluded from Figure 6.6 that the total EVR of the chain is about the same for both transport systems: 0.54 – 0.58

From the point of view of system design, it is more interesting to calculate data per net transport volume (litre), and group similar activities in the chain (as depicted in Figure 6.7):
- the transport packaging
- total of loading and unloading activity
- total of storage
- vehicle transport for "feeding" to the auction (leg 1)
- vehicle transport for "distribution" to the retail shops (leg 2)
- vehicle transport for the long distance (500 km).
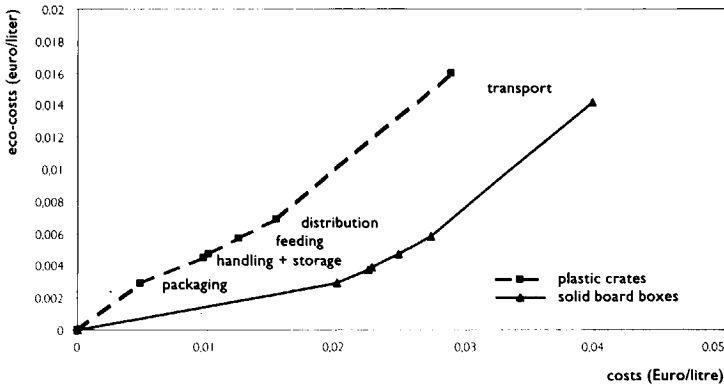
Fig. 6.7: Costs and eco-costs per litre net transport volume to Frankfurt (leg 2 is 500 km), including trans-
port packaging.
Note: The assumption is that no other return freight is transported in leg 2.

The main conclusions of Figure 6.7 are:
- the solid board system has lower eco-costs than the plastic crate system, not only
  for a transport distance in leg 2 (the leg Germany - Holland) of 500km, but also
  for short distances!
- the solid board system, however, is more expensive than the crate system.

The assumption for Figure 6.7 has been made that there is no other freight available
on the return leg. In practice, however, attempts are made to fill the trailers with
other freight for return leg 2 which results normally in 30-70% of "other" freight in
this leg. Figure 6.8 summarizes the effect this "return freight" as a function of percent
of the total of trailers return.
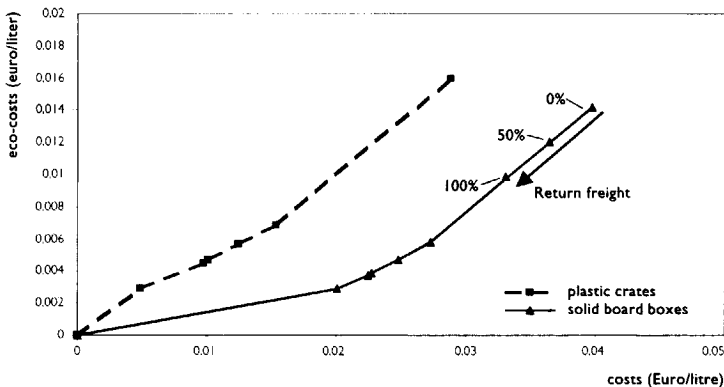
Fig. 6.8: Costs and eco-costs per litre net transport volume for the total chain (leg 2 is 500 km) as function
of the percentage return freight

Figure 6.8 shows that the difference of eco-costs between the solid board system and the crate system is becoming more relevant when the return trip can be used for other freight. When there is return freight, the differences in system costs get much smaller as well. Calculations show that for a distance of more than 800 km and 100% return freight, the costs of the solid board system become lower than the costs of a plastic crate system.

Although the crate system is cheaper for distances between 250 and 500 km, solid board boxes are still leading in this export market. This is because of two reasons:
- the perceived quality of the solid board boxes (as trays in the shops)
- the lack of international standardization of plastic crates[26].

So one may conclude that:
- the eco-costs of the solid board box systems are lower in all cases
- the overall ecocost/value ratio, the EVR of the crate system is 0.55
- the overall EVR of the solid board box system ranges from 0.36 – 0.30
- therefore the eco-efficiency of the system of solid board boxes, based on the definition of the WBCSD (Section 3), is considerably higher (eco-efficiency = 1 – EVR).

With regard to possible improvements of the packaging systems the following observations can be made:
- the crates have apparently been designed to minimize the use of materials: a redesign to maximize net transport volume (using perhaps a bit more material) is recommended since it will result in less costs and eco-costs of the total chain in terms of transport volume
- especially in big retail operations, the solid board boxes are hardly damaged in the chain, so the boxes might be used for two or three trips on average, which will bring down the costs for short distances to a level of the crate systems.

The EVR for each activity in Figure 6.7 has been calculated, resulting in the 9 EVR values for transport with truck+trailer:
- transport packaging, crates: 0.55
- transport packaging, solid board boxes: 0.15
- total of loading and unloading activity: 0.33
- total of storage, unconditioned: 0.34
- total of storage, conditioned: 0.57
- vehicle transport for feeding (50 km, 30 km/hour):   0.43
- vehicle transport for distribution (50 km, 30 km/hour):   0.43
- vehicle transport for medium distance (500 km, 70 km/hour):   0.67
- vehicle transport for long distance (1000 km, 80 km/hour):   0.72

The above list of EVR values enables a quick estimate of the total chain, when all costs per activity group are known.

[26] standardization of crates is a key-element of the system: when there are more types of crates in the system, storage, handling and cleaning of crates become rapidly cumbersome in terms of operations and related costs.

6.7 Conclusions

For the design of transport systems an integral LCA approach of the total transport chain (cycle) is required to minimize eco-costs. This is because of the high interaction of the system components: the packaging system, the transport system and the storage system. Efficient use of volume plays a key role as well as the re-use of packaging materials.

The eco-costs for the solid board box system appeared to be lower for all cases, especially when the truck can be used for other freight on the return trip. The EVR (and therefore the eco-efficiency) of the solid board box system is in all cases considerably better as well. So there is no reason from the environmental perspective to prefer plastic re-usable crates, which is an embarrassing conclusion in the light of the discussions in The Netherlands that started in the early nineties[27].

From an environmental perspective the analyses show that:
- plastic crates for fresh fruit and vegetables should be designed for maximum net volume content (instead of minimum materials for the crate) to optimize the use of the transport system (since the eco-costs of transport are more important than the eco-costs of the crates)
- for solid board boxes it remains important to lower the emissions during production (the best Dutch manufacturing facilities show already better LCA data than the average data which is used in this article)
- an attempt should be made to design the system of solid board boxes for two or three round trips per box for 'short distance & high volume' applications, to make them cost competitive for the short distances as well.

With regard to the application of the EVR model, it must be emphasised here that the analysis of this case was done according to the conventional rules for LCA: allocation was done on the basis of physical relationships. This allocation method required an extensive spreadsheet based computer program.

Applying the EVR and the economic allocation rules of Section 3, however, reveals the advantage of allocation by means of the EVR: *there are only 9 EVR values which determine the transport chain*. These 9 EVR values make quick assessments of eco-costs feasible, *without the extensive computer calculations*, when the cost structure of a transport chain is known (which is normally the case). The complex allocation problem is resolved by the EVR model: the designer of a transport system can assess the eco-costs of it by simply multiplying the costs and the corresponding EVR, and adding up the results. The EVR as a parameter for allocation resolves one of the major practical hurdles in the environmental assessment of complex product-service systems!

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[27] *in this situation 'durable' (= reusable) does not go hand in hand with 'sustainable', since other aspects of the total system play an important role.*

7. The eco-costs and the value of land conversion in The Netherlands

How the EVR model can be extended with a model for change of land-use

Abstract

This Section deals with research task 7: develop a single indicator for land-use

This Section describes the way land-use can be incorporated in the EVR model, as a decision support tool for the urban and rural planning aspects of expanding cities, industrial areas, road infrastructure, etc.
The so called 'eco-costs of land conversion' is proposed as a single indicator, being the marginal costs of prevention (or compensation) of the negative environmental effects of change of land-use. These 'eco-costs of land conversion' are based on four sustainability characteristics of land (before and after the conversion):
- the botanical aspects (the species richness and the rarity of ecosystems and vascular plants)
- the aspect of 'scenic beauty'
- the aspect of production of food and biomass
- the aspect of the H_2O cycle.

For the situation of The Netherlands (and the Western part of Europe), the eco-costs of the aspects 1 and 2 appear to be dominating.
Some practical examples are given on how to apply the model.

In the case of land-use, the economy and the ecology are normally in direct conflict with each other. Therefore extra attention is given to the economic value of a conversion and its consequences.

The methodology has been applied to a special case in The Netherlands: the A4 motorway connection Delft – Schiedam, Benelux tunnel (through an urban area and an area of scenic beauty).

7.1 Introduction: Land-use, LCA models and sustainability

7.1.1 Can land-use be integrated in LCA models?

The increasing use of land (urban areas, industrial areas, road infrastructure, etc.) is a major cause of degradation of our environment. In the last decennia there is a growing concern about this negative aspect of a growing population and a growing economic wealth. So, most of the LCA practitioners feel the need for incorporating the negative aspects of 'land-use'. But how?

The problems seem not so much related to boundary setting, nor with the 'direct' allocation. This is explained in the methodology report of the Eco-indicator '99 (Goedkoop et al., 1999) by the following example:
(quote) If we are analysing an electric razor, we know that the razor factory occupies a certain amount of space, let us assume 1 hectare. If the factory produces 1 million razors per year, we can say the hectare is needed during one millionth of a year for a single razor. However, we could also say that a single razor needs 1 square meter during 3.65 days (unquote)

The problem, however, is to characterize (quantify) the negative environmental impact of this "1 square meter during 3.65 days".
There is a fundamental methodological issue here with regard to the quoted example, since not all areas have the same importance with regard to the subject of sustainability. A production facility built in the middle of the national parcs, or, in the Dutch Waddenzee, generates considerably more ecological damage in terms of conversion of land than a production facility built in a desert area in Spain. Therefore, it does not make sense to base an analysis on 'the average square meter in Europe' (it is even hardly possible to create such an average).
In the example of the razors, the assumption is made that the exact product location is known, so the area is known, so the land-use can be expressed in a 'local' key indicator. But how realistic is it in the case of an existing production site to allocate exactly those square meters to those razors? (In most cases it is a matter of historical coincidences which lead to the production location of such a razor, and, would the sustainability of that razor be different if the production is transferred to another location?). So it becomes questionable whether it makes sense to allocate land-use to a razor, as it is done in the example!

The conclusion is that the simple reasoning of the example appears to have a fundamental methodological flaw, since it is doubtful that it is possible to reconcile the following contradicting system aspects of the razor example:
- the ecological damage of land-use, even in a relatively small region as The Netherlands, is related to local conditions (urban and rural planning), which requires a local approach
- industrial production, on the other hand, is global from a systems perspective, which requires a global approach.

The consequence seems to be that land-use in the LCAs of *industrial mass products* must be incorporated with great care. The allocation of land-use for production facilities and distribution centres to one single item of the product can often not be based on a causal physical relationship with specific pieces of land.

For materials it does make sense, however, to apply a global weighed average of the land-use parameters of mines (in case of metals), and of forests (in case of wood from natural rainforests).

It is also feasible to incorporate land-use in the LCA of a *one-off object*, such as a house, an office, a road, a bridge, a gravel pit, since such an object is per definition local. For these objects it is very relevant for decision makers to have an LCA-based tool available, including land-use, to decide on the location as to where to build the object.

Consequently, it is feasible to incorporate land-use in the LCA of specific products (such as yachts made at a specific wharf) and services (such as a tourist trip to a specific resort). An example will be given in chapter 7.6.2.

7.1.2 Modelling occupation or conversion of land

In the example of the razor in the previous chapter, the impact of land-use has been expressed in terms of *occupation* of land, with the dimension of (m^2.time). This relates to the idea that occupied land should be used in an effective and efficient way. A sustainable society should minimize the use of land for production purposes, and should strive for a maximum productivity per square meter. However, the question is whether productivity is an issue of environmental priority in Europe, since the mechanisms of the free market economy have already forced producers to maximize productivity (one may even argue that productivity has gone too far in some agricultural sectors like the bio-industry). So it does not seem logical to introduce the 'productivity of land-use' as the major sustainability parameter.

The other way to describe the impact of land-use is in terms of *conversion* of land (Finnveden, 1996), being the degradation of 'quality of land', with the dimension of (m^2). This relates to the idea that nature is being destroyed and the environment is degraded at the moment urban and industrial areas or railway and road infrastructure is expanded. The conversion of land causes depletion of scarce 'nature', similar to the resource depletion of materials when virgin materials are used for products.

Conversion of land is a topic in urban and rural planning in The Netherlands. Where to plan the expansion of cities? How to deal with the new infrastructure for roads and railways? Is it possible to compensate the loss of 'nature' and 'scenic beauty' by positive conversion (upgrading) of land in other areas, and how? For such dilemmas a model based on conversion seems most appropriate (Sala et al., 2000). To support the decision taking process, a single indicator for land has been developed, the so called eco-costs of land conversion.

7.1.3 The four main aspects of conversion of land in the EVR model

Use of land has the following four main 'endpoint categories' which are proposed with regard to sustainability (subjects which need to be protected):
1. 'habitat for plants, animals and other species' with biodiversity as an important 'impact category' with two aspects of botanical value 'species richness' or 'rare ecosystems' as the most important subcategories (indicators for fauna are still under development)
2. 'local habitat for the human being' with 'scenic beauty' as the main 'impact category'
3. 'food and energy production' with 'net biomass production' as the main 'impact category'
4. 'H_2O cycle function' with 'filter capacity', 'water storage' and 'desiccation' (Dutch: verdroging) as the main 'impact categories'.

Endpoint category 1 has been chosen in most cases to classify and characterize the subject of land-use (Lindeijer, 2000). The number of species counted on a piece of land (Köllner, 2000), the species richness, has widely been accepted as a characterization parameter for biodiversity in LCA studies. Most requirements and recommendations of ISO 14042 with regard to impact categories and indicators seem to be fulfilled. For the Netherlands, a refined model has been developed, based on rarity of ecosytems and their vascular plants (Witte, 1998)(Witte et al., 2000), operationalised by means of the Dutch FLORBASE database. It is also suitable to define which areas of nature are so rare that they should be protected (never be converted).
This endpoint category is dealt with in Chapter 7.2.

Endpoint category 2, with impact category 'scenic beauty' (being a term which is introduced in this thesis to denote aspects such as natural beauty, scenic beauty of landscapes and other visual and recreational aspects), has quite recently been introduced in the Dutch discussions on urban and rural planning. The basic idea is that the human being has the fundamental right to experience the pleasure of 'nature' not far from the cities, and that this is a sustainability issue. The fact that there is hardly any scientific literature on this subject (so it is hard to comply with all recommendations in the ISO 14042) is a disadvantage in creating a sound characterization model. However, the discussions on the modelling aspects of this impact category can best be triggered off by proposing a characterization model and key indicator.
Note: the fact that eco-costs are prevention based (and not damage based) is an advantage, since the damage of this impact category is harder to characterize than the prevention (or compensation). This endpoint category is dealt with in Chapter 7.3.

Endpoint category 3 has had a lot of attention in literature, see (Lindeijer, 2000). However, in The Netherlands (and Europe) the marginal prevention costs (in terms of compensation) appear to be negligible in comparison with the marginal prevention costs of category 1 and category 2. This is explained in Chapter 7.4

Endpoint category 4 (H_2O cycle function) is very important with respect to sustainability. This subject is so complex and divers (McKinney, 1998), that it seems hardly

feasible to include the related impact categories in de LCA modelling of land-use (occupation as well as conversion) in general. This endpoint category is quite important to The Netherlands as well. Chapter 7.5 deals with some major local issues. It is possible to develop the eco-costs for specific situations, as for Dutch polders, but general data cannot be provided since every situation is unique. The 'repair costs' of mistakes which have been made in the past are enormous, but 'prevention costs' are relatively low, and negligible in comparison with the eco-costs of scenic beauty.

The normal route to develop one single indicator for land conversion comprises two steps:
- For each impact category, a characterization model must be developed in order to create a category indicator for each subject (see ISO 14042).
- For each category indicator the marginal prevention costs must be estimated in order to make the conversion to the eco-costs, as a single indicator.
In the following chapters it will be shown how this will be applied to the 4 endpoint categories.

7.2 The eco-costs of land conversion in relation to botanical aspects

7.2.1 A choice between two impact categories: 'species richness' or 'rare ecosystems'

In this thesis two characterization systems for botanical value are proposed[28]:
a. a coarse system, based on the number of vascular plant species in a certain area, with the impact category 'species richness'
b. a more subtle system, based on the rarity of vascular plants and their ecosystems, with the impact category 'rare ecosystems'.

For each typical case, one has to make a choice between these systems (otherwise it would lead to double counting of the effect on botanical value). Each system has its pros and its cons.

The advantages of the system on species richness:
- it is the most commonly applied characterization system in the world of LCA practitioners
- it is relative simple and straight forward (the second order calculations, called 'regional effects' in the eco-indicator 99, have to be dissuaded though, as it is argued in the next chapter)
- data are available in many regions, and when they are not available it is feasible to gather indicative data or to predict the main characteristics based on general observations.

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[28] It has to be emphasised that botanical value is only one of the aspects of the endpoint category of 'habitat for plants, animals, birds, fish and other species'. Since characterization systems for the other aspects are still to be developed, the botanical value is for the time being the only characterization system which is operational.

The disadvantage is, however that it provides only a coarse, and in many cases inade-
quate, indication of the botanical value because:
-   all species add to the result in a positive sense, including the species that are part
    of disturbances (for instance: a heather has a higher species richness when it con-
    tains a weed-covered garbage)
-   certain highly valued but nevertheless species-poor ecosystems (bogs, salt marsh-
    es, drifting sand dunes, heatherlands) get too low a valuation
-   the system does not account for the fact that some species (especially the rare
    and threatened ones) are valued higher by nature conservationist than other
    species.

The system on 'rare ecosystems' does not have these disadvantages, since it:
-   only takes species into account that are indicative of the ecosystems considered
-   it uses the relative species richness of ecosystems, so that ecosystems that are
    species-poor by nature do no get a valuation which is too low
-   it takes the rarity of ecosystems into account (and, indirectly, also the rarity of
    species that occur in those ecosystems).

A disadvantages of the system on rare ecosystems is that the background of the sys-
tem is more complex and less easy to comprehend (a reasonable level of biological as
well as mathematical knowledge is required). Moreover, this system requires more
detailed information about the flora.

7.2.2 The characterization system and the category indicator for species richness

Species richness is characterized by the number of species of vascular plants at a cer-
tain area, S. It is one of the most applied measures of characterizing the botanical
aspects of land in LCAs (Lindeijer, 2000). For many Western European countries, data
on S are available. For The Netherlands field data are available on a grid of 1 km^2, see
Figure A.7.4., Annex 7e[29].

We express land-use in terms of 'actual m^2' x 'quality factor' of land before and after
the change. The quality factor is defined as the counted total number of vascular plant
species, S, divided by the quality norm for it, $S_{ref.}$, where $S_{ref.}$ is the number of species
for 1 km^2 of nature. We introduce now the category indicator for species richness of
land, SRI ('Species richness Indicator'), which is expressed in terms of the area, A (m^2),
multiplied by the quality factor for it, $S / S_{ref.}$

$$[7.1] \quad SRI = A * \frac{S}{S_{ref.}}$$

[29] Figure A.7.4. has been derived from FLORBASE. FLORBASE is a database with counted species of vascular
plants in the wild at a national grid of 1 km^2, 35.000 km^2 in total. This database is a compilation of data
from the Provinces, land owning organizations and institutes and from private persons.

So SRI is expressed in terms of 'equivalent m^2 of nature'.

The environmental effect of the change of land-use is described now as

[7.2] $\quad \Delta SRI = A * \dfrac{\Delta S}{S_{ref.}}$

where Δ denotes the difference of S and SRI before and after the change.

For the quality norm of S in The Netherlands, S_{ref}, a value of 250 vascular plants species for 1 km^2 is proposed. S is more than 250 for 11% of the total area of The Netherlands. (Areas above 300 are very scarce: 4% , areas above 200 are quite common: 25% , see Figure A.7.4, Annex 7e). For Germany, England and the northern part of France, the same quality norm of 250 species for 1 km^2 is proposed, since the species richness in these countries is in the same order of magnitude as in The Netherlands (Barthlott et al., 1998). For species richness of other countries, see Annex 7f.

When S is not available from a database, and when it is not feasible to count S in the field, one might apply a methodology to assess S on the basis on the CORINE land classification (http://etc.satellus.se/index.htm) combined with the size of such an area of land. In this Chapter, a calculation system is proposed which is in line with the basic approach of the 'Species-pool Effect Potential' of Köllner (Köllner, 2000) and the Eco-indicator '99 of Goedkoop (Goedkoop et al.,1999). The results of such calculations, however, must be regarded as a first order guestimates only, and must be interpreted with great care.

Köllner analysed data on S of various types of land as a function of the size of that type of land, applying the following correlation of S as a function of the size of the area:

[7.3a] $S = S_{1\ ha} (A_{TA})^b$

where:
-   $S_{1\ ha}$ is the counted number of species (vascular plants) on 1 hectare (= 0.01 km^2) of a certain type of land
-   A_{TA} is the actual size of the total area (hectare) of that type of land
-   b is the 'species accumulation rate' (the slope of the correlation between the measured value of S and the size of the area on log-log paper).

Table 7.1 provides the data of Köllner for $S_{1\ ha}$ and b, and subsequent calculations of S for other areas, according to equation [7.3].
-   The data of Köllner are based on sample sizes of 1 to 20 ha. Calculation of data by equation [7.3] might slightly be extrapolated (1 ha < A_{TA} < 100 ha). Further extrapolation is not allowed[30].

[30] *Above 1 km^2, the value of b is expected to drop drastically to a value below 0.2 (Witte, 1998), (Witte et al., 2001). For The Netherlands in total (S = 1550 for 35.000 km^2) b= 0.097 starting from the maximum S (564 for 1 km^2).*

- For areas smaller than 1 km^2, $S_{ref.}$ in equation [7.1] and [7.2] is proposed to change according to

[7.3b] $S_{ref.} = 137.5 * (A_{TA})b$, where $b = 0.13$ (resulting in $S_{ref.} = 250$ for 1 km^2)

see also Table 7.1

Example 1:

When an area of 0.2 km^2 (=20 ha = 200,000 m^2) is converted totally from 'industrial fallow' to 'industrial area' or to 'intensive meadow' , the net effect on SRI in terms of 'equivalent m^2 of nature' can be calculated as follows (combining equation [7.1] and applying Table 7.1):

- the SRI of the 'industrial fallow' is:
  $A * S / S_{ref.} = 200,000 \times 191 / 203 = 188,817$ equiv. m^2
- the SRI of the 'industrial area' is:
  $A * S / S_{ref.} = 200,000 \times 155 / 203 = 134,783$ equiv. m^2
- the SRI of the 'intensive meadow' is:
  $A * S / S_{ref.} = 200,000 \times 53 / 203 = 52,217$ equiv. m^2
- the net loss of SRI, ΔSRI, of the conversion of 0.2 km^2 'industrial fallow' to 'industrial area' is 54,034 equiv. m^2 of nature
- the net loss of SRI, ΔSRI of the conversion of 0.2 km^2 'industrial fallow' to 'intensive meadow' is 136,600 equiv. m^2 of nature

In example 1, the total area was converted, and there was no interaction with adjacent areas. When, however, an area is expanded by converting a part of an adjacent area, the total effect on the SRI is more complex. In such a case, the theoretical increase or decrease of SRI stems from three factors:

1. conversion of land itself ('first order effect')
2. increase of S in the total area which is expanded ('second order effect' because of the increase of area in equation [7.3])
3. decrease of S in the total remaining adjacent area ('second order effect' because of the decrease of area in equation [7.3]).

The mathematical consequences of the second order effect (point 2 and 3) are provided in Annex 7a, where this second order effect is also applied to the case where a piece of land is partitioned in two e.g. by a motorway. These second order calculations, however, have to be applied with great care, since they often do not reflect the reality for many reasons:

- b in equation [7.3] is a function of the size of the area (Witte et al., 2001)
- an underlying assumption of the second order calculations is that species are equally distributed over an area, but this is normally not the case (Witte, 1998)
- the conversion of land is normally related to human activities which have a positive secondary effect on S (creation of ditches, verges, hedges and other activities which creates new small scale ecosystems)
- the values of b in Table 7.1 have been derived from curve fits on log-log paper (Köllner, 2000), which results in fairly inaccurate values (differentiation is than hardly allowed)
- this method of species richness gives only a coarse indication of the botanical

value of the land (Witte, 1998); differentiation of the equations "to become more accurate" does not make sense then.

One may conclude therefore that the second order calculations on S are not recommended, and that the first order calculations on the basis of Table 7.1 and equation [7.3] must be interpreted with great care. It is therefor highly recommended to apply the actual data from the field, as provided in databases like FLOBASE.

7.2.3 The eco-costs for species richness

The conversion of a category indicator to the single indicator of the EVR model, the eco-costs, is based on either the prevention costs or the compensation costs. For SRI the compensation costs are taken as the yard stick.

The costs related to the creation of a protected nature area are estimated as:
-   3.5 Euro per m^2 to buy the land (price of agricultural land in the Western part of Europe in 2000)
-   0.5 Euro per m^2 for the conversion costs (Sijtsma et al., 1995).

The resulting total costs of compensation, the eco-costs of species richness, are:
4 Euro per equivalent m^2 of nature. In formula:

[7.4]   *eco-costs of species richness* = ΔSRI $*$ *4 (Euro)*

Where ΔSRI is the difference between SRI before and after the conversion.

Equation [7.4] might be applied or The Netherlands, Belgium, Germany, England and the northern part of France. For other countries in the world, a preliminary calculation method of the eco-costs is proposed in Annex 7f.

7.2.4 The characterization system and the category indicator for 'rare ecosystems'

A much more subtle methodology of botanical characterization on the basis of counting of species (vascular plants), is a methodology developed by Witte (Witte, 1998). This methodology takes the rarity of plants and ecosystems into account. Although species richness is an indicator for botanical value (when there are many species, there are normally valuable species as well), it is a logical step forward to distinguish between species which are important and species which are less important. Witte took 'rarity of eco-systems' as a main measure of importance. They operationalised the methodology by means of the Dutch FLORBASE database. This database contains distribution data of species that grow in the wild in a national grid of The Netherlands (35.000 km^2 in total). Data is available of 28,000 areas of one km^2, being over 80% of the total area. For a summary of the methodology, see Annex 7b.

The basic idea behind this methodology is that every specific ecosystem in The

Netherlands (there are 28 of them) has its own specific types of vascular plant species. The methodology results in a score for 'botanical value of one km^2', Q:

[7.5] $Q = \sum (V \times C)$ where $0 < C < 1$, and for The Netherlands $1 < V < 10$

V is a parameter for the rarity of an 'ecosystem type' and C is a parameter for the completeness (in that km^2) of an ecosystem type in terms of 'indicator plants' for that ecosystem type (indicator plants are plants which occur only in one, two, or maximum 3 ecosystems). The summation is to cope with the case that there are more than one ecosystem within 1 km^2. C can be calculated by:

[7.6] $C = \dfrac{(N - 0.43\, N_{0.2})}{(0.29\, N_{0.2})}$ $\qquad$ for $0.43 < \dfrac{N}{N_{0.2}} < 0.72$

$\qquad$ $C = 0$ $\qquad\qquad$ for $\dfrac{N}{N_{0.2}} < 0.43$

$\qquad$ $C = 1$ $\qquad\qquad$ for $\dfrac{N}{N_{0.2}} > 0.72$

N is a weighted number of indicator species, and $N_{0.2}$ is the maximum weighed number of indicator species for that ecosystem in The Netherlands, both per km^2. See Annex 7b. The factor 0.43 in equation [7.6] means that a threshold is applied for C. Land such as intensive meadow and intensive arable have a score $C = 0$, and therefore $Q = 0$, in this system.

Equation [7.5] is used now to define the category indicator in the LCA methodology. The category indicator for botanical rarity of land, ERI ('Ecosystems Rarity Indicator'), will be expressed in terms of the area, A (m^2), multiplied by ($Q / Q_{threshold}$).

[7.7a] $ERI = A * \dfrac{Q}{Q_{threshold}}$

So ERI is expressed in terms of 'equivalent m^2 of rare ecosystems'. The norm, $Q_{threshold}$, has to be determined on the basis of "what is rare (in The Netherlands) ?".

In Annex 7b a threshold norm is proposed for the ecosystem rarity:

[7.7b] $Q_{threshold} = 3.3$

The botanical value Q is higher than 3.3 for 20% of the total real area of The Netherlands. Basically, it is a political choice in our society where to put the norm for

the threshold. In Annex 7e a map of Q in the Netherlands shows these and other threshold levels. The basic idea about the threshold value is that if $Q / Q_{threshold}$ is more than 1, the botanical value of nature is of such an importance that these areas have to be protected (never be converted).

7.2.5 The eco-costs for 'rare ecosystems'.

The conversion of the category indicator ERI to the single indicator of the EVR model, the eco-costs, is based on two principles:
a. when $(Q / Q_{threshold})$ is more than 1, the conversion of land must be prevented (for-bidden), since compensation (relocation) of rare ecosystems is often not feasible
b. when $(Q / Q_{threshold})$ is less than 1, compensation of the conversion of land might be considered since relocation of the ecosystem is assumed to be feasible.

For case a, it is not possible to give a general indication of the related eco-costs (pre-vention costs), since costs to prevent the conversion (leave the area of nature intact) will differ for each typical location. For case b, the total costs of compensation are based on the costs which are related to the creation of a protected area of nature elsewhere (see Chapter 7.2.3). The eco-costs of rare ecosystems, are: 4 Euro per equivalent m^2 of nature.

In formula:

[7.8]   *eco-costs of rare ecosystems* $= \Delta ERI * 4 = 4 \times A \times \Delta \dfrac{Q}{Q_{threshold}}$ *(Euro)*

for $(Q / Q_{threshold})$ before conversion < 1 , where $Q_{threshold} = 3.3$ and

where Δ denotes the difference between Q and ERI before and after the conversion

It is obvious that either equation [7.8] or equation [7.4] has to be applied (to avoid 'double counting'). Note that equation [7.8] is zero for intensively used land, caused by the threshold value in [7.6].

7.3 The eco-costs of land conversion in relation to scenic beauty

7.3.1 The characterization system and the category indicator for scenic beauty

The impact category of 'scenic beauty' is related to urban and rural planning. The basic idea is that the human being has the fundamental right to experience the pleas-ure of 'nature' (natural beauty, scenic beauty of landscapes and other visual and recre-ational aspects of parks and landscapes). This 'green land' has to be planned not far from the cities, since the need for travelling over long distances has to be kept to a minimum. Scenic beauty is considered as an elementary aspect of the human welfare, should be protected, and is therefore a sustainability issue. It has quite recently been

introduced in the Dutch policy of urban and rural master planning. Unfortunately, there is yet hardly any scientific work available on this subject related to the LCA methodology. Some research has been done in this field (Hoffmans, 1998), but LCA characterization systems are still to be shaped. This chapter has to be regarded as a first attempt (proposal) to do so, hopefully triggering off further developments.
The density of people, P (number of people per hectare), is the chosen primary measure of characterizing the importance of scenic beauty (the more people around who can enjoy this beauty, the higher the characterization factor). Other factors are:
- SBR, the Scenic Beauty Ratio: a factor characterizing the beauty as such
- CHR, the Cultural Heritage Ratio: a factor characterizing the cultural heritage of special objects involved
- PSR, the Perceived Scarcity Ratio: a factor characterizing the perceived scarcity of 'green areas' (city parks and the like).

Scenic beauty in The Netherlands is man-made (Van der Woud, 1987), (Reh et al., 1999). The sheer fact that the area has not yet been covered with buildings, roads etc. is enough to have the opportunity of developing it for the future (Steenbergen et al., 1996).So the actual status of the scenic beauty is not so important in terms of sustainability. Therefore SBR = 1 for all types of 'green land', and SBR = 0 for built-up areas, roads, etc.

Sometimes scenic beauty is determined by monumental buildings, picturesque houses and farms, windmills of before 1900, etc. It is obvious that this should be kept intact. A characterization system, however, is still to be developed, so for the time being CHR = 1.

Especially in cities, where the density of population can get quite high (P is more than 30), people locally get the feeling that 'green land' (city parks) becomes extremely scarce, and should never be converted to 'built-up area'. This perceived scarcity of 'green areas' is dealt with by the local factor PSR, in the eco-costs model defined by:

$$[7.9] \quad PSR = \frac{total\ area}{(total\ area - built\text{-}up\ area)} \text{, see also Note}^{31}$$

The category indicator for scenic beauty of land, SI ('Scenic Importance'), will be expressed in terms of the area, A (m^2), multiplied by the regional people density factor, P / P_{norm}, and the perceived scarcity factor, PSR / PSR_{norm}, resulting in:

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[31] *The value of (total area − built-up area) can be regarded as the area which can be converted in parks ('green area') in the future. In suburbs the local PSR is normally about 2, but in city centres it can become more than 10.*

$$[7.10] \; SI = A * \left(\frac{P}{P_{norm}} \right) * \left(\frac{PSR}{PSR_{norm}} \right)$$

So SI is expressed in terms of 'equivalent m^2 of scenic beauty'.

The data of the province of Zuid-Holland have been taken for the norms of P and PSR for The Netherlands, since this province has the highest density of population:
P_{norm} = 11.8 people per ha (= 1180 people per km^2)
PSR_{norm} = 1.21 (average value over the total province).

Remarks:
- Any other province could have been taken as the norm: it does not effect the methodology (e.g. the comparison between 2 or more areas), but only effects the numeric values.
- The term (P / P_{norm}) x (PSR / PSR_{norm}) can be smaller than one (e.g. other provinces) as well as bigger than one (e.g. local values of PSR for city centres).
- When PSR is bigger than e.g. 10 (such a value is a political choice), conversion should be forbidden since local compensation is often not feasible.

Regional values for P and PSR are provided in Table 7.3 for the 12 provinces in The Netherlands. In general it is advised to define the region size for P within the range of 2000 – 5000 km (the size of the region is related to the fact that 'scenic beauty' has to be close enough to the cities). It is advised to base the local values for PSR on an area of 10 – 25 km^2 (related to a limited distance of citizens and their local parks).

7.3.2 The eco-costs for scenic beauty

The conversion of the category indicator SI to the single indicator of the EVR model, the eco-costs, is based on the marginal prevention costs as a yardstick. The basic idea is that conversion of 'green areas' into 'built-up areas' has to be avoided from the 'scenic beauty' point of view.

Measures of prevention are, in order of increasing costs:
a. enhance the density of industrial areas (less open space, medium or high rise warehouses)
b. enhance the density of population of built-up areas (try to accommodate more housing in cities)
c. cover roads and railway lines
d. build underground (underground parking lots and shopping centres, tunnels for roads and railways).

Annex 7c shows some technical measures of prevention, with cost estimates.

The basic idea of the marginal prevention costs is depicted in Figure 7.1. The assumption is that all technical measures (curve a) to a certain level of prevention (the norm

for sustainability) are being applied to prevent the need for the conversion of 'green areas' to 'built-up areas'. The 'last' measure in terms of costs (the most expensive measure) determines the marginal prevention costs (Euro/m^2) of land conversion, and is the norm for it (the slope of line b).
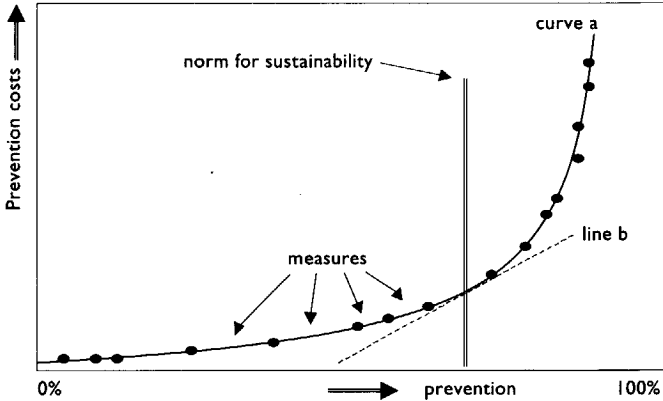
Fig. 7.1: The marginal prevention costs of land conversion.

In the methodology of the marginal prevention costs, the problem now is to determine the norm for sustainability: which measures of Annex 7c have to be taken to reach a sustainable situation? There are basically two ways to determine the norm:
1. the 'political will' or 'willingness to pay' (as it has been done for Land Fill, see chapter 4.4.1)
2. a steady state calculation (as it has been done for emissions, see chapter 2.5).

Both ways can result in a norm:
1. Although the 'political will' is hard to establish in The Netherlands on the subject of urban and rural planning (the Dutch have a very complex system in terms of decision taking, with quite some influence from local pressure groups), the 'willingness to pay' by the public might lead to a norm: in some cases there is an indication on the level of acceptable marginal prevention costs[32]: 450 Euro/m^2
2. Under the assumption that a steady state for the Province of Zuid Holland is acceptable for the future ("either no conversion, or compensation elsewhere" is the norm for sustainability), the marginal prevention costs for sustainability can be determined. A steady state (= no conversion or full compensation) is hard to

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[32] Example: For the 'HSL-Zuid' railway track it was decided by the government to tunnel 7 km under 'scenic beauty' at a cost of 400,000,000 Euro (57,000,000 Euro per km), which was generally considered by the newspapers as 'too expensive' for the case. A proposal to lower the adjacent track of 2 km for an extra costs of 22,000,000 Euro (11,000,000 Euro per km) was refused by the government at first, but finally it was accepted, after a lot of pressure from society.. Apparently the 'political will' is quite fluctuating, but the 'willingness to pay' of the Dutch society is probably near 11 million Euro per km. With a width of the track of 25 m, this equals 450 Euro per m^2.

achieve in areas with a fast growing population, however, a steady state in The Netherlands for the coming 50 years is quite possible[33]. In order to assess the feasibility of a steady state, a complex computer program is required, similar to MARKAL (see chapter 3.3.2). Such a computer program is not (yet) available, but some preliminary estimates show the feasibility of a steady state:

- the massive increase of 'houses with little gardens' seems not to fit the market demand: the market value per m^2 of houses in cities is considerably higher than the market value of houses in rural areas; there is need for more houses within the big cities
- more than 10% - 20% higher density of housing in the cities seems quite feasible (Heimans, 1968) by renovation of the districts which have been built before 1950; the market prices are such that these renovations are feasible from the economic point of view: it is a matter of political will now
- a more intensive use of industrial terrain is quite feasible (high rise warehouses, etc.), at an extra costs level which is below 100 Euro/m^2
- fast growing transportation of people and goods, however, seems to claim a bigger and bigger area of land; the solution here is to cover roads and railway lines and shunting yards; the extra costs (the marginal prevention costs) have been estimated at 450 Euro/m^2 (see Annex 7c).

So it has been decided to set the norm at a level of 450 Euro/m^2 for the marginal prevention costs. This norm is related to the situation in the province of Zuid-Holland, where Zuid-Holland is charcterized by P_{norm} = 11.8 inhabitants per hectare and where the average PSR is 1.21.

In other words, the resulting eco-costs of scenic beauty are:
450 Euro per 'equivalent m^2 of scenic beauty'

Referring to equation [7.10], the eco-costs are defined as:

[7.11] eco-costs of scenic beauty = $\Delta SI * 450$ (Euro)

   where ΔSI is the difference of SI before and after the conversion

Table 7.3 provides the data on eco-costs per actual m^2 (from 'green land' to 'built-up') for the 12 Dutch provinces.

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[33] The growth of Dutch population will slow down. The maximum population for The Netherlands is estimated at 17.5 million people (this maximum will be reached in the year 2035). This is only 10% more than the Dutch population in 2000 (15.85 million).

7.4 The eco-costs of land conversion in relation to biomass production

7.4.1 The characterization system and the category indicator of biomass production

The endpoint category 'food and energy production'[34] has had a lot of attention in literature, with 'biomass production' as the main 'impact category' (Lindeijer, 2000).

The characterization system for biomass production can be based on the Net Primary Production (NPP) in kilogram dry materials or in kilogram Carbon per square meter of land (Sas et al., 1996). NPP is chosen here as yardstick for biomass production, but is also a yardstick on how effective land is used as a sink for CO_2 in the energy cycle. The NPP is the total biomass growth. 'Net' is used here in terms of the CO_2 cycle: it is the amount of Carbon that is captured in the plant. You can harvest only a certain percentage of the NPP (the roots of the plants stay behind), which has been be called the NCP - "Net Consumption Productivity"- (Lindeijer, 2000). The NCP depends on the soil conditions, the climate and the biomass production management.

The tendency in production management to strive for a maximum economic yield has caused a situation where there is no shortage in food production in Western Europe and in the USA. However, this maximization of yield has lead to serious environmental pollution, and to erosion in some areas. In The Netherlands, eutrophication is the major problem. The low quality of freshwater runoff from agricultural land has caused an excess of nutrients in the soil, the groundwater and the surface water, causing many ecological problems (like dying fish because of excess of algae in lakes and canals). It is estimated that, when the fertilization of the land in The Netherlands is reduced to a sustainable level, the agricultural production will decline by 5% (Dellink et al., 1997). Such a reduced production is taken as the sustainable norm: $NCP_{sustainable}$.

The category indicator for biomass production, BMI ('BioMass Indicator'), will be expressed in terms of the area, A (m^2), multiplied by the actual NCP, and divided by the sustainability norm for it, $NCP_{sustainable}$.

$$[7.12]\ BMI = A * \frac{NCP}{NCP_{sustainable}}$$

So BMI is expressed in terms of 'equivalent m^2 of biomass production'
And for intensive meadow and intensive arable in the Dutch region:

$$[7.13]\ \frac{NCP}{NCP_{sustainable}} = NCP * \frac{1}{0.95}$$

[34] This endpoint category is the basis for a single indicator model called "the ecological foodprint" (Rees, 2000), in which the total area is calculated which is required for one citizen in an economy which is totally based on biomass.

To support biolife and to avoid erosion, it is proposed in literature to harvest less of the NPP than what can be harvested as a maximum, and leave the remainder on the land, this remainder is the so called Free Net Primary Production FNPP (Lindeijer, 2000b). So, FNPP = NPP – NCP. In Western Europe there is a surplus of nutrients rather than a shortage. However, in other areas where erosion is a problem, like the Mid West of the USA and the northern part of China, $NCP_{sustainable}$ equals the NPP minus the minimum required FNPP for sustainable production.

7.4.2 The eco-costs of land for biomass production

The conversion of the category indicator BMI to the single indicator of the EVR model, the eco-costs, is based on compensation costs as a form of marginal prevention costs. The basic idea is here that agricultural production and forestry can be shifted eastward within Europe. Agricultural land and forests can be bought in the former East Block Countries[35] and can be converted from a rather low NCP to a normal NCP by modern management techniques, of course within the limits of sustainable agriculture and forestry.

The costs related to such a shift of production is rather low:
- less than 0.45 Euro per m^2 for the costs of agricultural land
- less than 0.05 Euro per m^2 for the costs to convert the land to modern biomass production.

The resulting total costs of compensation, the eco-costs of land for biomass production, are:
- 0.5 Euro per equivalent m^2 of land for biomass production.

In formula:

[7.14] *eco-costs of land for biomass production = ∆BMI ∗ 0.5 (Euro)*

   where ∆BMI is the difference of BMI before and after the conversion.

Note that the low level of eco-costs of land for biomass production is in line with the idea of many people that biomass production is not an important 'endpoint category' with regard to sustainability (not a subject that needs to be protected), but rather an issue of agricultural and forestry management and an issue of international politics. On the global level, land is still abundantly available, but often badly mismanaged. Only when biomass will be applied for production of fuels (ethanol) on a wide scale, scarcity of land for biomass production might come into the picture again.

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[35] *There are major opportunities to enhance the NPP by modern agricultural management and modern forestry - within sustainable limits - in countries like Poland, Estonia, Latvia, Lithuania, White Russia and the Ukraine.*

7.5 The eco-costs of land conversion for the H₂O cycle function

7.5.1 The main aspects of the H₂O cycle function in relation to land conversion

The main functions of land in the H_2O cycle are the filtering (cleansing) function and the storage function of fresh water. Unfortunately, the importance of these functions were neglected for decades. Only recently is there sufficient awareness that these functions are real sustainability issues, and that "water management" is an indispensable activity for the future.

The main issues for The Netherlands are:
1. Floods of the rivers Rhine and Meuse are getting dangerously higher because of two factors:
   a. the water storage function upstream is less, resulting in sharper peak levels downstream
   b. the winter riverbed is smaller downstream (the area between winter dikes has been made smaller in the past to gain land for housing and the like)
   c. there are hardly any possibilities for water storage (possibilities to inundate land) to buffer peaks within The Netherlands.
2. The surface area of the lakes and canals in the western part of The Netherlands is too small, resulting in a too low storage volume of fresh water. The adverse affects for the polders are that:
   a. at instances of heavy rainfall land is flooded, since the water cannot be pumped away fast enough
   b. in dry periods polluted water from the river Rhine is supplied (to maintain the ground water level in polders), causing pollution of the soil
3. Ground water is polluted because of pollution of the soil above it.
4. The water level is kept too low for 'wet species' (wet species require a ground water level of $0 - 50$ cm with an average of 25 cm, especially in spring). The reason for this desiccation of the surface area is that, either adjacent areas require lower water levels for commercial reasons such as agricultural production (in wet areas), or too much drinking water is being extracted (in dry areas).

The situation for these 4 main problems is that the measures which have to be taken do not have the characteristics of *prevention*, but have the characteristics of repair. Mismanagement in the past has to be corrected in the future at enormous costs for the Dutch society:
- to correct the situation of the first issue, $2.3 - 3.8$ billion Euro is required, involving up to 110,000 hectare of land (V&W, 2000)
- to correct the situation of the second issue (enhancing either the pumping and transport capacity, or enhancing the total water storage), 2 - 3 billion Euro is required, involving up to 100,000 hectare of land (CPB, 2000)
- to correct the situation of the third issue, the current estimate is that over 50 billion Euro (!) is needed to bring the situation back to 'acceptable' proportions (the target is here a political decision based on technical and economical feasibility)
- to correct the situation of the fourth issue, relatively minor costs are involved; the

problem is though "who pays ?" since there is no commercial interest to restore the current situation.

It is good to realise that the repair costs are a multiple of the prevention costs for each of these issues: in the past, the right decisions could have been taken in time at virtually no extra costs.

7.5.2 The eco-costs of land conversion for the H_2O cycle function (in urban areas)

In terms of a sustainability, mistakes which have been made in the past should be avoided in the future. This means that extra measures have to be taken at the conversion from 'green areas' to 'built-up areas', to prevent disturbance of the H_2O cycle function. These measures comprise:
1. create a fresh water storage volume to cope with excessive rainfall in the area, either by enough surface water area or by enough infiltration capacity
2. keep the rain water sewage system separated from the domestic water sewage system and supply houses with separate systems for potable water and rain water (rain water can be applied for flushing toilets, irrigating gardens, cleaning cars, etc.)
3. keep the ground water at a constant level to avoid damage to the ecosystem.

Characterization systems and norms for sustainability are still to be developed and there are no general cost figures for these measures: each situation is unique and requires its unique technical measures (Van de Ven, 1999). Therefore, it is not (yet) possible to create a category indicator and a corresponding value for the eco-costs of land conversion for the H_2O cycle function.

For specific cases, however, the 'marginal prevention costs' for the aforementioned four measures for conversion of land can be calculated. For those cases, one can make a cost estimate on the difference of "what is done" and "what should be done", and one can decide on "the last measure to be taken" to create a sustainable situation. For projects which are under development now in the Dutch polders, these marginal prevention costs are estimated to be less than 4 Euro per m^2, being much less than the eco-costs of scenic beauty. See Annex 7d for the methodology for the Dutch polders. So the eco-costs of the H_2O cycle can be neglected.

7.6 The EVR (Eco-costs / Value Ratio) of land conversion

7.6.1 The value of land

The market value of land varies enormously by its destined use (in The Netherlands the use of land is restricted by law to its destined use):
a. areas for agriculture (and forestry)
b. industrial areas
c. areas where houses can be built.
The price of land for agriculture is restricted by the economics of farming. The cur-

rent price is 3 – 4 Euro per m^2 (good quality land has that same price in other EC countries as well), which is considered to be the maximum at the current interest rate (about 6% for mortgages) to make profit as a farmer. The price of industrial areas is determined by municipalities (controlled by local politics) and is sometimes kept low to attract industry to the region. Current prices range from zero to 150 Euro/m^2. The price of land for houses is determined by its scarcity, basically a result of national master planning, and local rural and urban planning. Current prices range from 100 Euo/m^2 in the Northern provinces to 500 Euro/m^2 near Amsterdam, Utrecht, The Hague and Rotterdam.

Municipalities can earn a lot of money by buying agricultural land, re-defining the destined use into a housing area, create the required infrastructure of roads, sewerage, electricity and gas, and sell the land in the free market for houses. The same applies to industrial areas, although the profit which can be made is less. It is obvious that such a phenomenon induces private speculation in land prices as well.

Since there is this financial incentive for municipalities to convert the destination of land from 'green areas' to 'built-up areas', there has been a tendency in the past to convert agricultural areas into areas with houses, rather than enhancement of the density of population in the cities. This phenomenon should be stopped, e.g. by taking away the financial benefits of conversion, which might be done by introducing 'state conversion tax'[36].

7.6.2 The Eco-costs / Value Ratio (EVR) of land conversion and allocation in the LCA

In the EVR model, land-use is treated similarly to the use of materials in the LCA of an object:
- for the use of 'virgin' materials, a penalty in the form of 'eco-costs of materials depletion' has to be taken into account in calculating the total eco-costs of the Life Cycle (see Section 4)
- similarly, for the conversion of 'green' land, a penalty in the form of 'eco-costs of land conversion' has to be added to the total eco-costs of the Life Cycle, to account for the conversion (depletion) of biodiversity and scenic beauty
- when recycled materials are applied, there is no penalty for materials depletion (eco-costs of materials depletion = 0)
- similarly, when land is re-used, there is neither change of biodiversity, nor change in scenic beauty, so there is no penalty in terms of eco-costs.

Such a system stimulates the re-use of land.
Comparing the eco-costs in Table 7.3 with current prices for land in The Netherlands

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[36] *The problem here is that the public interest of well-being is opposite to the local or private financial interest. Since such a tax is on conversion only, it effects only new conversions. It is comparable with 'tradable emission rights' for emissions. The level of the tax might be equal to the financial benefit of the conversion, or equal to the eco-costs of land conversion. The state tax income might be spent on positive conversions (creating national parks).*

(August 2000), it can be concluded that the EVR of land in The Netherlands ranges from 0.5 to 1.5 for areas with houses. The EVR of land for industrial areas is normally higher than 2.

Allocation of the eco-costs is done on the basis of the economic lifetime of the object on a linear basis.

Example 2.
A small, new, wharf for leisure yachts has an annual turnover of 1 million Euro. It has been built on a piece of 'less intensive meadow' of 10,000 m^2 (S=40) in the province of Noord-Holland. The expected economical lifetime of the wharf is 30 years. The following calculation shows how the eco-costs of land conversion are allocated to one yacht of 100,000 Euro:

- *eco-costs of species richness = 4 * SRI = 4 * 10,000 * S / S$_{ref.}$ = 40,000 * 40/250 = 6,400 Euro (equations [7.1] and [7.4] and Table 7.1)*
- *eco-costs of scenic beauty = 450 * SI = 450 * 10,000 * (P / P$_{norm}$) * (PSR / PSR$_{norm}$) = 450 * 10,000 * 0.80 * 0.98 = 3,528,000 Euro (equation [7.6] and [7.11] and Table 7.3)*
- *eco-costs of land conversion = eco-costs of species richness + eco-costs of scenic beauty = 3,534,400 Euro*
- *eco-costs of land conversion per year = 3,534,400 / 30 = 117,813 Euro per year*
- *eco-costs of land conversion of the yacht = 117,813 * (market value yacht) / (annual turnover wharf) = 11,781 Euro*

7.7 Case: a new motorway (the A4 from Delft to Schiedam)

As an example on how to apply the eco-costs of species richness and the eco-costs of scenic beauty in real life situations, the A4 motorway has been analysed. This motorway is to be built between Delft and Schiedam in the Dutch province of Zuid Holland. See the map of Figure 7.2

Fig. 7.2 The proposed route of the A4 motorway between Delft and Schiedam.

This motorway is an essential link between the area of The Hague and the Port of Rotterdam, but local action groups in the city of Schiedam and environmentalists have been opposing it successfully for the last two decades. Proposals have been made for the road through the city, showing that a 'covered solution' (a small park on top of the motorway, combined with an adjacent shopping centre) is attractive from the financial point of view. The financial benefits of a maximum usage of the strip of land in the centre of the city seem to be higher that the extra costs of the combined con-struction (De Ridder et al., 1999).

The route through the polder Delfland, however, is still under discussion between environmentalists and the government. Delfland is an important area of 'less intensive meadow', important from the point of view of botanical value as well as scenic beauty. The total area of about 20 km^2 is split in two parts (40% - 60%).

The level of 'botanical value of one km^2' is not above the 2% threshold (Q < 3.3), see Annex 7e, so there is no need to cancel the project because of rarity of nature.

In this case the eco-costs of scenic beauty are by far the highest eco-costs.
The eco-costs of scenic beauty can be calculated, applying equations [7.10] and [7.11] for a strip of land of 3.5 km (length) $*$ 25 m (width) = 87,500 m^2.
For the province of Zuid Holland (see Table 7.3), equation [7.10] results in:
$\Delta SI = A * (P / P_{norm}) \times (PSR / PSR_{norm}) = 87,500 * 1 * 1 = 87,500$ 'equivalent m^2 of scenic beauty', resulting in (equation [7.11]):
*eco-costs of scenic beauty = 87,500 * 450 = 39.4 million Euro*

The eco-costs of rare ecosystems and/or species richness (equation [7.8] and/or equation [7.4]) are more than a factor 100 lower than the eco-costs of scenic beauty. This might seem astonishing for the reader, but it is well in line with the main protest against the construction of this road: "we should not ruin this area of nature so close to the cities: it is of high value for the citizens to relax and enjoy this area of nature and scenic beauty" (an argument related to the endpoint category 'local habitat for the human being' rather than the endpoint category 'habitat for plants, animals and other species', see Chapter 7.1.3 and also the discussion in Chapter 7.9). Equation [A.7.16] for the H$_2$O cycle function leads in this case also to negligible eco-costs of land conversion (ΔII is estimated to be here less than 0.5, resulting in eco-costs of less than 0.5 Euro per m^2).

In this case we have tried to apply the second order equations for species richness as well[37]. The results, however, has to be regarded with great care:
- the choice of the size of the affected area is rather arbitrary (it is far from an island)
- the area contains many small ecosystems (instead of one ecosystem)
- the value of *b* is not known (and probably will never ever be known, since the area is not homogenous).

So the total eco-costs are about 39.4 million Euro. Note that these costs are virtual

costs: they are a norm for the marginal prevention costs to achieve a sustainable society. The actual (local) prevention costs may be lower or higher (see Figure 7.1). When the actual prevention costs are lower, it does make sense to take the actual prevention measure, however, when the actual prevention costs are higher, it makes sense to use the money to apply a compensation measure elsewhere. In this case it appears that the actual costs are higher (De Ridder et al., 1999). This is related to the problematic local soil conditions. So it seems wiser, from national point of view to use the 39.4 million Euro for compensation:
- either to resolve a similar problem elsewhere in the province of Zuid Holland,
- or use the 39.4 million Euro to create a big park in the same area of 20 km^2 (about 8 Euro per m^2 is a fair estimate of the required costs to do so).

It is interesting to look at the economic value side of the project as well (De Ridder et al., 1999). The construction costs of a normal road (without any extra measures) is about 190 million Euro for the total length of 6.3 km. The economic value for the users of the new connection has been estimated at 630 million Euro (the Net Present Value over 25 years of the savings of citizens, transport companies and other business users). So there is an enormous economic interest to build this road. Given the economic value, there is no reason to abandon any plan for compensation of the aspects of sustainability!

7.8 Conclusions

It is feasible to determine the eco-costs of land conversion for specific situations according to the scheme of Figure 7.3.

In the calculation scheme of Figure 7.3 it is shown that two category indicators can be used for the endpoint category 'habitat for plants': either SRI (for species richness) or ERI (for rarity of ecosystems). For ERI a threshold value has been built in: when ERI is more that 1 conversion should be forbidden. For the endpoint category 'H$_2$O cycle', a cate gory indicator is still to be developed for the conversion from green areas to built-up areas. Therefore the eco-costs can only be determined in specific cases. The eco-costs tend to be low compared to the eco-costs of scenic beauty.

[37] *The eco-costs of species richness can be calculated, applying equations [7.3], [A.7.7] and [7.4] for 'less intensive meadow'. Since the area is approximately 20 km^2 , it is to big to apply equation [7.2]. We assume for S a value of 230, being the S count per km^2, according to [7.3] (In this case S can be derived from FLORBASE, see Annex 7e, to determine the actual situation before the conversion). Furthermore we assume that b = 0.2. Equation [7.3] results in:*
$SRI_{original} = A * S / S_{ref.} = 20,000,000 * 230 / 250 = 18,400,000$ 'equivalent m^2 of nature'
Equation [A.7.7] results in a loss of SRI of:
$\Delta SRI = SRI_{original} * \{ 1 - \beta^{1+b} - (1-\beta)^{1+b} \} = 18,400,000 * 0.13 = 2,392,000$ 'equivalent m^2 of nature'
Resulting in (equation [7.4]):
*eco-costs of species richness = 2,392,000 * 4 = 9.5 million Euro.*

endpoint category	habitat for plants		local habitat people	food and biomass	H$_2$O cycle
impact category	species richness	rare eco-systems	scenic beauty	biomass prod.	- buffer cap. - filter cap. - desiccation
category indicator (equiv.m2)	SRI	ERI	SI	BMI	II (Dutch polders)
eco-costs (Euro)	Δ SRI x 4	or Δ ERI x 4	Δ SI x 450	Δ BMI x 0,5	< Δ II x 6

$$\text{Prevention (= "conversion forbidden") if: } \frac{ERI}{A} > 1$$
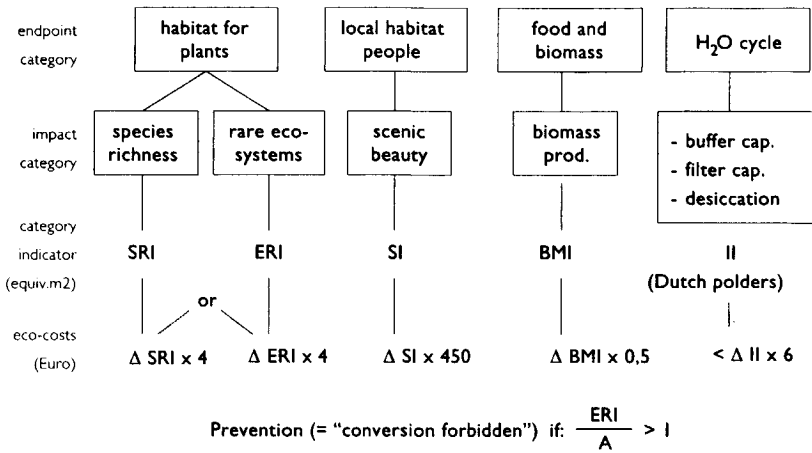
Fig. 7.3: The calculation scheme of the eco-costs of land conversion.

In calculations of eco-costs, two aspects seem to be dominating:

a. the botanical valuation of nature, in situations where a green area is converted to a green area of an other type

b. the scenic beauty, in situations where green land in urban areas is converted to built-up land.

7.9 Discussion

Relative importance of 'scenic beauty' and 'nature'.
A striking aspect of the model for eco-costs of land conversion is the fact that the eco-costs of scenic beauty in The Netherlands are a factor 15-110 higher that the eco-costs of nature. It triggers the question: "is 'scenic beauty' that much more important than 'nature'?".
The answer is twofold:

a. Local habitat for people, i.e. scenic beauty, is locally important for densely populated areas like The Netherlands. Application of the given equations for eco-costs on a global scale, however, shows that species richness is the ruling indicator for over 90% of the global area.

b. The eco-costs are not about the importance (value) of something, the eco-costs are about the marginal prevention costs. See chapter 2.3. The eco-costs as a single indicator tells us something about the difference in costs of "what we do" and "what we should do in terms of sustainability". When the eco-costs are low, it means that it is not very expensive for our society to do something about it. From that point of view, we should not hesitate to take the appropriate actions to conserve 'nature' (in terms of prevention as well as compensation)!

The relationship between eco-costs and value (the EVR of land conversion).
Another aspect of the eco-costs of conversion of land is that there appears to be a

weak relationship between those eco-costs (the marginal prevention costs) and economic value. The reason for this is that the marginal prevention costs for land conversion are related to the compensation costs, and the compensation costs are correlated to the economic value.

For example:

- the EVR of the conversion from green areas to built-up areas for housing is in most of the practical cases in the range from 0.5 to 1.5
- the EVR of the conversion from nature to agricultural ranges from 0.7 to 1.3.

The EVR of the conversion from green areas to industrial areas (including horticultural areas) is much higher in most of the cases: 2 or (much) more. This stems from the political paradigm that industry has to be attracted to reduce the unemployment. From the point of view of sustainability, this type of 'hidden subsidy' should be abandoned.

Design and engineering of products and spatial planning.
With regard to design and engineering, the eco-costs for land-use can be applied for:
a. assessment of the alternative solutions for spatial planning (e.g. in urban and rural planning)
b. a single indicator for conversion of land in LCA calculations.

In the case of the assessment of alternative solutions for spatial planning, the calculations on eco-costs of land-use can be applied to determine measures for compensation. In such a situation it makes sense that the compensation has to done within each endpoint category separately (e.g. negative effects on the H_2O cycle have to be compensated by positive measures in the field of the H_2O cycle, and not in the field of botanical value or scenic beauty). Furthermore it makes sense to incorporate the noise disturbance by roads, and the eco-costs of it, in such assessments of alternative solutions for spatial planning. See Annex 10.

In the case of an LCA, it is obvious that the exact locations for production sites and warehouses have to be known to be able to assess the required data for the eco-costs of land conversion. This means that incorporation of land-use in an LCA only makes sense for specific or one-off products, as it has been mentioned already in Chapter 7.1.1. A special issue in the LCA methodology is the land-use for mining of metals and fossil fuels, and the land-use effects of wood from rainforests. For those materials the weighted average eco-costs for species richness might be applied, as it has been indicated in Annex 7f.

8. Communicating the eco-efficiency of products and services by means of the EVR Model

Experiments with selection of the best out of 4 cases by the 3 stakeholders:
Consumers, Business representatives and Governmental representatives

Abstract

This Section deals with research task 8: establish the hurdles in communication of environmental issues and relate them to the new model.

In this Section, an experiment is described to test whether the EVR model leads to a good understanding of the eco-efficiency of a product-service combination. In this experiment 3 separate groups of 8-11 people were asked to rank four alternative solutions of a product-service system (the after sales service and the maintenance service of an induction plate cooker) in terms of sustainability. The 3 respective groups were:
- *customers (among whom representatives of consumer organizations)*
- *business representatives from the manufacturing company of the induction plate cookers*
- *governmental representatives (employees of the Dutch ministries of environmental affairs and economic affairs, and of the Dutch provinces as well as consultants involved in governmental policies), all experts in the field of sustainability.*

The basic idea was to ask each group to rank the 4 alternative solutions in terms of the best expected environmental performance after three levels of information input:
- *the first level of information was basic explanation of the 4 alternatives (without environmental data), with which some major features and characteristics (like price) were given,*
- *then LCA data were explained and added to the information (9 environmental impact classes and the eco-indicator '95),*
- *finally the eco-costs and the EVR data were given after a short explanation of the concept..*

Each time the group was asked to rank the proposed alternatives in terms of "best sustainability" as well in terms of "best choice in general", and why. Furthermore it was asked what information was missing to make "the right" decision on the ranking (as it was perceived by the participants). At the end it was asked whether the eco-costs and the EVR were perceived as good criteria on which to base decisions.

In the customers and business representatives group (where the majority of participants were non-experts) the ranking changed when more information was given. They finally based their decisions on the eco-costs/value model. The governmental group (all experts), however, tended to stick more to their original ranking and especially to the eco-indicator '95.

From the experiments it can be concluded that:
- *The concept of Eco-costs was accepted by the majority of the non-experts, better than LCA output on which to base their ranking.*
- *The concept of the EVR was understood by the majority of the non-experts, but the consequences of it in terms of life style were not easily accepted (the consumers group especially rejected the idea of having their life style judged by an eco-efficiency parameter).*
- *The environmental experts in the governmental group did not directly accept the concept of eco-costs model (they wanted in depth information first); they tend to stick to their existing knowledge of LCA data.*
- *"Overall" preferences of the customers and business representatives were primarily ranked on the 'perceived value'/ costs ratio of the product-service combination; the sustainability of the product-service combination played a secondary role.*

The opportunity has been taken to question the participants of 3 groups about their paradigms on the roles and interaction of the 3 stakeholders on the road to sustainability (13 questions). The environmental experts among the participants seem to place the "moral duty to take care of the environment" above everything, so above the economics necessary to attain this (some of them expressed that they were averse to make monetary calculations when dealing with sustainability).

8.1 The challenge: communicating the issue of eco-efficiency

In the interrelation between companies, consumers/citizens and governments (see Figure 8.1), sustainability will become more important in the near future (sustainability will become of greater "value" to the citizen). So the importance of understanding eco-efficiency by all stakeholders involved will grow. In the required shift towards more eco-efficiency (uncoupling economy and ecology by a factor 4 or even more), each stakeholder group will play its own role:
- consumers/citizens have to shift their expenditures towards a lower Eco-cost / Value Ratio
- companies have to create product-service combinations with a lower Eco-costs / Value Ratio
- governments have to create regulations and new systems for tax and subsidies.

A good interaction between stakeholder groups require good communication on the subject, which requires all stakeholders to "speak the same language".
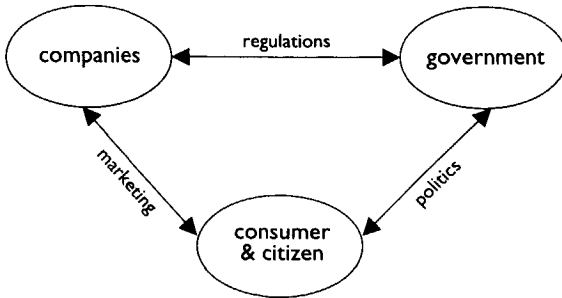
Fig. 8.1: The 3 stakeholders and their main interactions.

Currently there seems to be a communication gap between environmental specialists and each of the stakeholders. Environmental specialists regularly try to make the situation clear by showing the results of LCAs and the *environmental impacts* of products and processes. However, results of an LCA are complex to understand (environmental specialists tend to stress that as well), and environmental impacts have an even more complex cause-effect relationship. Many discussions in science about impact, the complexity of the calculations, and problems with setting priorities, make stakeholders aware of the imminent problems, but do not make clear how to tackle the problem (Moisander, 1999).

Our presuppositions before the experiment were the following:
- Most business representatives are assessing sustainability issues only in terms of: "what does it cost for my company and how can I create a competitive edge for my own company in the market". As such they are not very interested in impact assessments and other LCA details.
- Most citizens are "consumers" when they are buying products: they look for a good costs/value ratio. They do not feel they can do anything (on their own) with the overwhelming and gloomy environmental analyses (Uusitalo, 1999).
- Most governments struggle with priority setting, not knowing how to rank different environmental effects. How can they apply the outputs of LCAs?

It can be concluded that there is nothing wrong with LCAs as such, but they tend to fail to provide answers in the right form to stakeholders. The main question for stakeholders is: What do we have to *do* about the problem in our own sphere of influence? The answer to all problems of environmental specialists - less consumption and less production - seems not to be accepted by the stakeholders. What the stakeholders are really asking for is a way of uncoupling economy and ecology (eco-efficiency), in other words: creating more value with less eco-costs.

Since the Eco-costs / Value Model is LCA based and since it defines eco-efficiency, this model could be used to solve the aforementioned problem. The question, however, is: Can this model be communicated to the stakeholders? Do they understand the underlying principles without complex explanations? And do they accept the concept then as realistic and a 'useful tool' to realise a sustainable society?

So the idea was born to test the concept by asking stakeholders to decide on a real life problem: selecting the best alternative out of four options. The case is the after sales service and maintenance system of an induction plate cooker: which concept is the best in terms of sustainability?

In the following chapters the induction plate cooker and the 4 concepts of after sales service and maintenance is described first. Then the methodology is described as well as the setting of the experiment. Thereafter the results of the experiment are given and conclusions are drawn. Finally the results are presented of a questionnaire (13 questions) on the roles and interaction of the 3 stakeholders on the road to sustainability, as depicted in Figure 8.1.

8.2 Four concepts of after sales service and maintenance of an induction-plate cooker

The product chosen for this experiment is an induction-plate cooker of the ATAG Kitchen Group, a "high quality" product with a premium price (approx. 1800 Euro) which can be purchased with a "full guarantee" for 10 years. See figure 8.2. The service which is chosen for the experiment is the after sales service for this product.
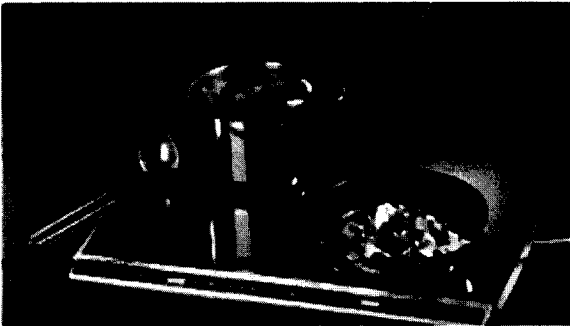
Fig. 8.2: The object of the study: a induction plate cooker.

For the experiment we developed 4 different types of hypothetical service concepts, described below.
A. "Conventional", being the classic type of after sales service (repair):
- in case of a break down, the client calls the company
- the telephone operator will ask what the problem is
- the after sales service planning department will schedule the local service engineer within 24 hours
- the logistic system will deliver the required parts overnight to the van of the service engineer
- the engineer is able to repair the induction plate cooker in 70% of the cases; in 30% of the cases he needs to visit a second time because he has not been able to repair the product the first time.

B. "The first time right", being a situation were 100% of the cases are repaired the first time:
  - by adding the right diagnostic software to the product, the telephone operator knows exactly what is wrong
  - the planning department knows the repair time
  - the logistic system will bring the right parts.

  Note: an induction plate cooker has already a lot of control software, so adding diagnostic software can be done relatively cheaply (4.5 to 9 Euro extra per cooker, which is less than 0.5% of the price). Major advantage: the client will not be disappointed and there will be less pollution since the service engineer will drive less kilometres.

C. "Easy to repair by the client"
  - the product will be of a modular design (easy clips, screws for click-on and plug-in)
  - a repair guide on the web site and a help desk will guide the customer through repair actions
  - ordering new parts (= modules) by E-mail or at the help desk, delivery by post next morning.

  Note: making the product modular is estimated to add 35 Euro per cooker to the sales price (2%). Major advantage: the client does not need to stay home, and there will be less pollution since there is no need for service engineer kilometres.

D. "Designed for less maintenance", reducing maintenance by 60%
  - it appears that 60% of all repairs is caused by the failure of 2 specific circuit boards
  - it is possible to design these parts "trouble free" either by adding redundant boards, or by heavy testing
  - however, the price for this solution is about 180 Euro (10% of the purchase price) extra.
  - advantage: reliable product; enhanced durability of the product.

  Note: "maintenance free" is not possible without a price increase of more than 50%.

8.3 The experiment

The basic idea of the experiment was to provide the participants stepwise with more information on the environmental aspects of the 4 after sales concepts, and monitor whether the opinion of the participants would change as a reaction to this information and if so, how.

The programme of one session had a duration of 4 hours and comprised the steps shown in Figure 8.3.

Questionnaire on 13 issues
("paradigm of the participants")

Short explanation of 4 alternative services

First ranking:
• Which concept is best from an environmental point of view and why?
• What more information would you need to make a better selection?
• Which concept do you prefer in general and why?

Short explanation of the LCA and Eco-indicator '95

Second ranking:
• Which concept is best from an environmental point of view and why?
• What more information would you need to make a better selection?
• Which concept do you prefer in general and why?

Short explanation of the eco-costs and EVR

Third ranking:
• Which concept is best from an environmental point of view and why?
• What more information would you need to make a better selection?
• Which concept do you prefer in general and why?

Explanation of an extra service: a 'real' cookbook or
a 'virtual' one on the internet

Which is your favourite choice and why?

Questionnaire on the concept of eco-costs and EVR

Group discussion

Fig. 8.3: The flow-chart of the experiment.

For the experiment the Group Decision Room Computer System of the University of Delft was used. The advantage of such a system is that the voting, ranking and comments are done anonymously, so without interference (influence) of the other participants. In these sessions the comments of the participants were labelled with code names (every participant created his or her own code name, like a password). This was done to be able to keep track of the individual comments during the session. The disadvantage of such an approach of anonymous participants, however, is that specific characteristics of the individual participants (like age, education, etc.) were not known. It was only after the session that we realised (by studying the comments) that experts reacted differently in comparison with non-experts, causing major differences between the governmental group (100% experts) and the other groups (approx. 20% experts).

Although the real information on the environmental aspects is very complex in nature, the concepts were shown in an extremely short time span. Only 5 minutes to explain the basic concept of an LCA and the eco-indicator '95, 5 minutes to explain the concept of eco-costs (no explanation of how these costs are calculated) and less than 5 minutes for the EVR (eco-costs versus value charts, eco-payout time). So especially on the EVR concepts, hardly any time was spend to reflect on it. Many aspects were 'thrown on the table' just to check what was 'understood intuitively' [38]. The 3 groups got the same information (so the information was not 'adapted' to the group). Only the final discussion was focussed on the primary interest of the group, and was therefore different for each session.

With regard to the first, second and third ranking of preferences (Figure 8.3), the questions to be tested were:
- Do people change their preferences when they are confronted with data on sustainability? (Evaluated from the question, "Which concept do you prefer in general")
- Do people accept the outcome of a certain model of environmental calculations, only after a very short description of the model? (Evaluated from the question, "Which concept - of after sale service - is best from the environmental point of view")
- Do people change their minds when they are confronted with the concept of eco-costs and EVR after being confronted with the concept of the eco-indicator '95? (They might become confused when they discover that there are more models to assess the sustainability of a product. Do they switch their opinion within such a short time span? Do they prefer the eco-costs and do they accept it?)
- Do people feel that they need more information to choose (at each step of the programme), and if so what kind of information?

8.4 The environmental data

Data were derived from the existing situation of the after sales service and on the

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[38] Another motive to keep the explanation very short was to avoid a situation where participants would have got the feeling that the EVR was 'promoted'. Therefore a well balanced time schedule was aimed at.

required additional personnel and investments for each department: the call centre, the logistic departments, the service engineers and the administration and "overheads". Furthermore operational data were gathered like number of repairs per day per engineer, average kilometres per client, characteristics of the repairs, average costs of parts, etc.

The LCA data of Figure 8.4 and 8.5 were calculated by means of the Simapro computer program (www.pre.nl).
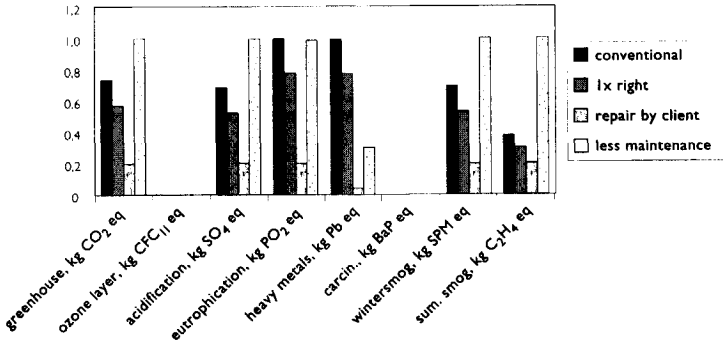
Fig. 8.4: The relative emissions of 8 pollution classes for the 4 maintenance concepts.
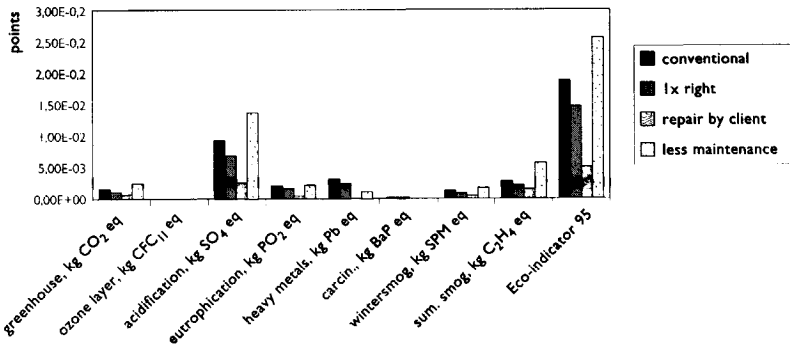
Fig. 8.5: The emissions in "points" of the eco-indicator '95 for the 4 maintenance concepts.

In the sessions an eco-costs versus costs chart was shown on the 4 maintenance concepts, with a short explanation of the sections in each curve see Figure 8.6 and 8.7. Figure 8.6 depicts the eco-costs and the costs of the various activities which are involved in the repair of the induction plate cooker in the conventional way (as it is described in chapter 8.2):
-   the *preparation*, including the call centre, the planning and the logistics of the parts
-   *driving* to and from the client of the service engineer
-   *repair* of the cooker at the home of the client
-   the *overheads* of the organization.

In Figure 8.7 the eco-costs are shown for the four alternative concepts of after sales:
-   for "first time right" the savings are in driving, repair and overheads
-   for "repair by client" there is no driving and repair by the service engineer, but the cooker is more expensive and contains more material (the "last leg" of the line)
-   for "less maintenance" there are 60% savings on the repair (first time right) but the cooker is 10% more expensive and contains more material (the last leg of the line).
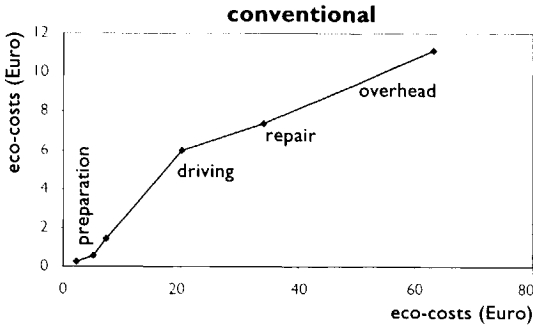
Fig. 8.6: The eco-costs versus costs chart of conventional repair of the induction plate cooker.
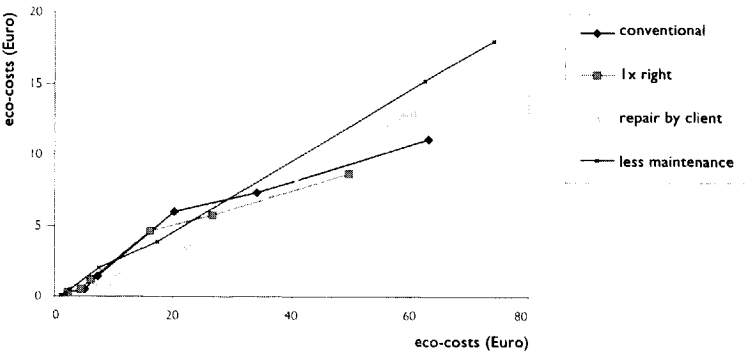
Fig. 8.7: The eco-costs versus costs chart of the four concepts of after sales service of the cooker.

To be able to check the preferences of the participant of an additional service, the participants were asked whether they preferred (either as a gift or with an extra payment):
-   either a glossy cookbook (recipes adapted to the special advantages of having an induction type plate cooker)
-   or having access to a special web site with the latest recipes for induction cooking.

The test was basically *why* people made their specific choice. Was the choice only based on their own perception of the value or the value/price ratio, or did the sustainability aspect (eco-costs or the EVR) play a role?. The eco-costs versus costs chart of Figure 8.8 was shown as part of the information to base the choice on. (Note: This chart is also an excellent example of the uncoupling principle.)
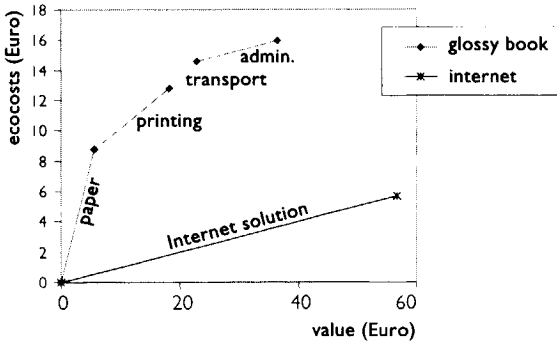
Fig. 8.8: The eco-costs versus costs chart of a glossy cookery-book and a web site cookery-book.

8.5 The results of the experiments

8.5.1 Ranking test of the consumers group and the business representatives group

The consumers group and business representatives group on the one hand and the government representatives on the other hand are dealt with separately because the last group consisted of mainly specialists. The results of the first, second and third ranking of preferences for the session with the consumers and the session with business representatives is depicted in Figure 8.9a, 8.9b and Figure 8.10a, 8.10b.
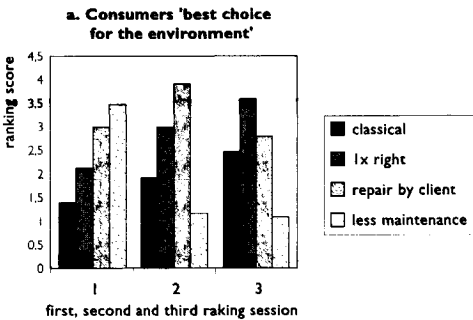
Fig. 8.9a: Consumers group environmental ranking.
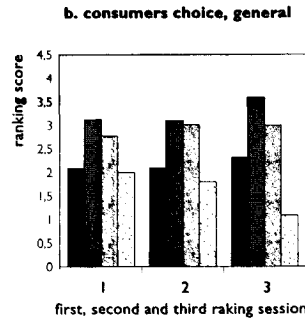
Fig. 8.9b: Consumers group preferences.

The consumers group and the business representatives group were amazingly similar in their choices on ranking of "best choice for the environment" (top store is 4; least score is 1), see Figure 8.9a and 8.10a. They both changed their opinion in each ranking session. They both started with the "guts feel" that "less maintenance" was equivalent to a longer "lifetime", and therefore better for the environment. In later ranking sessions they realised that there was a heavy penalty for it in the extra material required in the cooker.
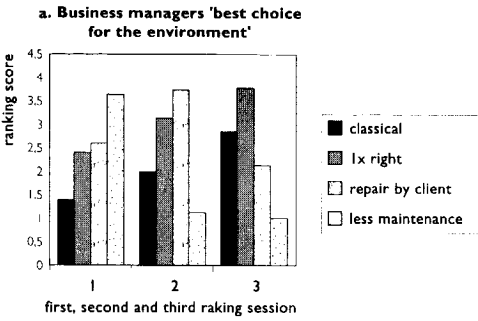
Fig. 8.10a: Business representatives group environmental ranking.
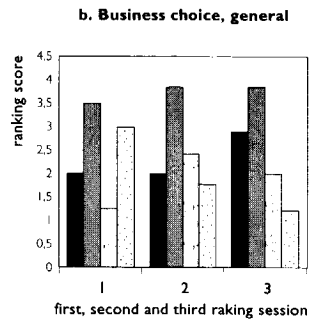
Fig. 8.10b: Business representatives preferences.

Detailed analyses of the sessions showed that both in the consumers group and in the business representatives group, in the third ranking session only 1 out of the 8 participants had chosen for the eco-indicator model instead of the eco-costs model on which to base their ranking (it was explicitly asked to make a decision on which model to use). In the consumers group was this only 1 out of 9 participants.

The difference of ranking on "the best choice, general" between the two groups was also minor: the main difference is that the consumers ranked "repair by client" higher than the business representatives. In both groups "the best choice, general" was only slightly influenced by the environmental information. On the basis of the comments on the question why a certain alternative was chosen, it could be concluded that the environmental aspects play only a secondary role[39] in the choice, as depicted in Figure 8.11. When the price/value ratio does already leads to a conclusive choice, customers do not take environmental aspects into consideration anymore. Only when there is no preference on the basis of price/value, environmental issues do help consumers make their final selection.
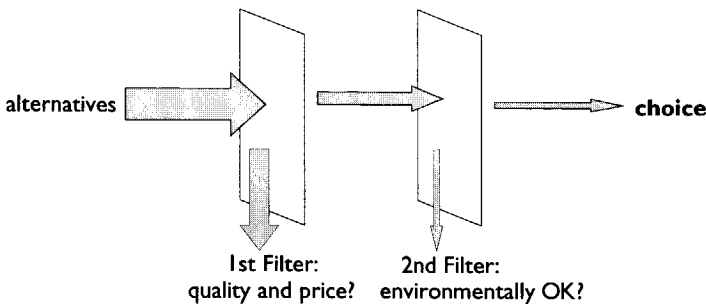
Fig. 8.11: Environmental data serve only as a second order filter in the decision of consumers.

[39] Such a secundary role in the marketing of environmental aspects was also suggested in (Santema et al., 1994).

8.5.2 Ranking test of the group of governmental representatives.

The ranking test of the governmental group revealed a totally different pattern! See Figure 8.12a and 8.12b.
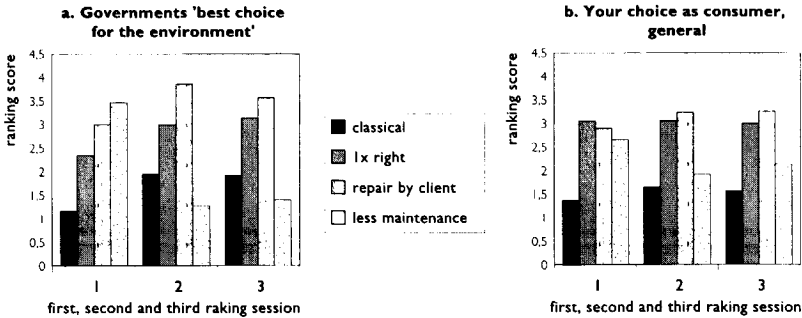
Fig. 8.12a: Government group environmental Ranking.   Fig. 8.12b: Government group preferences.

The major difference with the other groups is in the third ranking session of the question "what is the best choice for the environment", Figure 8.12a.: the third ranking does not differ significantly from the second ranking session! This means that the governmental representatives didn't use the eco-cost model as the preferred model. Analyses of the comments "why?" revealed that this seemed to be related to the fact that the participants were all experts in the field of sustainability, and were already acquainted with the LCA theories and with the eco-indicator '95 model. Furthermore, they tend to (as most environmental experts do) "place the environmental issues above the economy" as is revealed by the questionnaires, dealt with hereafter.

Only 3 out of 11 participants used the eco-cost versus cost chart to make the third ranking. Analyses of the comments of the other 8 participants revealed that the reason to reject the new model fell in one of the four following categories:
- I do not accept a monetary calculation since it is not allowed to compare ecology with economy; the choice for ecology is a fundamental one, regardless of the economic consequences to reach sustainability
- I see a new method which might be interesting, but I do not see yet the consequences of the model, so I reject it for the time being
- I want to know the details of the model first before I can accept it
- I am used to the eco-indicator '95, so I do not see why I should accept a new model.

Concluding:"it requires more that 10 minutes to convince the expert that a model is worthwhile to apply", which could be expected!

8.5.3 The additional service: a cookbook for induction cooking

As a last test, two questions were asked with regard of the cookery-book depicted in Figure 8.8 of Chapter 5:
1. "which offer do you prefer as a customer and why?"
2. "do you have the opinion that the government should support (e.g. subsidise pilots, etc.) the internet solution".

Since this additional service is an extreme example of a product which is eco-efficient (high costs at a low environmental burden, so a low EVR) with a product which is not so eco-efficient, it was interesting to see what the reaction would be. The test was not focussed on the preference book versus internet, but was focussed on the "why": was sustainability part of the consideration, or not.

Unfortunately there was a time squeeze on the consumers, a good test is not available for this group. So the results in Table 8.2 are only provided for the business group and the government group.

It may be concluded that sustainability hardly plays any role in the decision when a big difference in value of the product is perceived (the consumer preference is so strong that environmental issues are not considered anymore), which again supports the idea that sustainability in consumers choices play only a secondary role (Figure 8.11). It is obvious that in the government group (experts) more participants weighed sustainability in their decision than in the business group.

8.5.4 The questionnaires

The opportunity has been taken to question the participants of 3 groups about their paradigms on the roles and interaction of the 3 stakeholders on the road to sustainability (Figure 8.1, Chapter 8.2). Thirteen questions and the way they were answered in the three groups are given in the Table 8.4. This table shows that on the majority of the issues the three groups had the same opinion. The different opinions (where the majority of a group was different from the majority of other groups):
-   the government group and the consumers group had the opinion that the government should not limit the amount of money to be spent on environmental issues (question 10),
-   the government group and the customers group are of the opinion that the citizens determine via politics how much money they are prepared to spend on environmental issues (question 9),
-   the government group voted with a rather big majority that they didn't agree with the following statement (question 13): "Governmental regulations that place our national industry in an unfavourable competitive position should not be allowed" (only 2 out of 11 agreed);
    while the business group did agree 100%; the consumers opinions were divided.

At the end of the session, the participants were asked to give their opinion on the

new model. These results have been combined with the information on the aforementioned ranking (see Figures 8.9, 8.10, and 8.11, and the explanatory text). Combining these data gives the "overall" test results of Table 8.3.

Apparently, the consumers and business representatives tend to accept such a model on the general philosophy and not on the full understanding of it. The experts of the government group react the other way around: they only accept it when they fully understand. In the verbal discussion it was expressed by some participants that "reliability" of calculations in the field of environmental issues is becoming a bigger and bigger problem in general ("who should we believe?").

From the verbal discussion with the consumers group it was concluded that the participants had grasped the principles of the EVR amazingly well, but rejected the idea to judge on their life style by such an eco-efficiency parameter. This is probably related to the fact that there is still quite a gap between environmental awareness and environmental behaviour in The Netherlands (Steg, 1999).

8.6 Indicative results and conclusions

In order to reach a sustainable society it is important that government, business and consumers understand the concept of eco-efficiency. For this they need certain information on which to base their decisions. Current environmental information, like LCA, fails to provide the right answers to stakeholders in terms of decision support. The new eco-costs/ value model aims to solve this problem but still needs to be communicated to the stakeholders and understood and accepted by them.

The experiment revealed that the consumers and business representatives (non-experts) accepted the new model, even after a short explanation. They accepted it intuitively on the general philosophy, without a real understanding of the complete model. They understood the idea of eco-costs and even meaning of the EVR (Eco-costs Value Ratio). The government representatives (experts), on the other hand, did not accept the new model and stuck with the eco-indicator 95 information, which was given earlier during the experiment. They did not see the need for a new model (they were specialists after all, not having trouble with LCA data) or did not accept the monetary nature of the model or had too many questions before they could accept it. According to the theory of diffusion of innovation (Rogers, 1962), it is common that expert groups stick to existing theories, rather than accepting new ideas. Rogers studies revealed that these groups can be convinced only by 'opinion leaders' in their own profession. See annex 8.

These results show that for all three groups a tailor-made introduction strategy for the new model has to be made. It was not so much the model itself which was being questioned (it seemed to fulfil an existing need) but secondary (emotional) aspects seem to play a very important role at the introduction of the model.

The general impression of the whole experiment is that:
- the aspect of sustainability plays hardly any role in the decision when a consumer has a strong preference (based on other aspects) for a certain product type
- however, the aspect of sustainability can play a quite important role in the decision when there is no preference on other grounds.

This suggests that a real "break through" (in terms of impact on sustainability) in green marketing can be expected only when the aspect of sustainability is dealt with in terms of the 'second order filter' of Figure 8.11. Especially for commodity products and services (note that maintenance is a 'commodity service') 'sustainability' can be made the distinguishing factor of choice. A precondition is that sustainability has to be communicated in terms of a reliable number (where possible together with a certification system). For "high end" products in the market however, sustainability might better be "built in" other aspects of the perceived quality of a product like "low energy" and "durability" (Section 5).

It is recommended to test the above conclusions on a bigger, randomly selected, group of people.
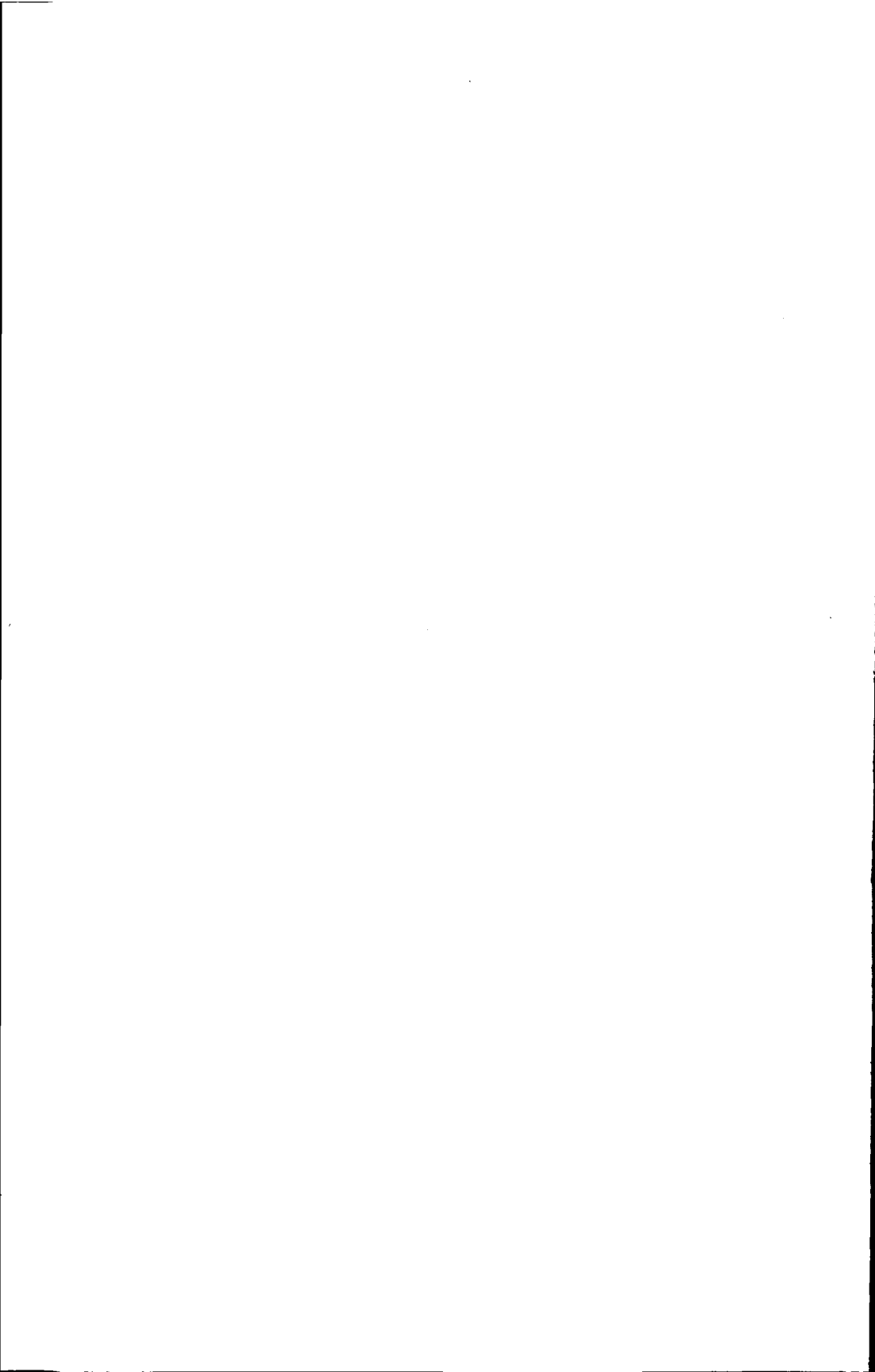
9. The EVR model as a tool for designers and decision makers

The road towards sustainability

Abstract

This Section deals with research task 9: define the consequences for companies and governments.

This Section deals with the 'the road towards sustainability'. What can we learn from the EVR model in terms of consequences for our current society? Which opportunities are there for the de-linking of economy and ecology? What is the role of companies and the governments, and which kind of decisions have to be taken to support the transition from the present state of our economy towards a sustainable economy?

In order to describe the mechanism of the required transition, the 'three stakeholders model' is introduced. This model provides the main interactions between business, government and consumers/citizens with regard to the issue of sustainability:
- citizens ask the government to care for their long term interests and to create sustainability
- the government defines regulatory frameworks and has to create a level playing field for the industry
- the industry satisfies short term consumer needs in terms of maximum value for money.

Understanding the mechanisms within the three stakeholders model and understanding the ways to enhance the EVR can lead to sustainable strategies in companies and sustainable policies in governments.

A product portfolio management strategy is proposed where companies take their products with a high cost/value ratio and enhance the EVR of these products (starting off with products with low eco-costs and then try to enhance their cost/value ratio, as many environmentalists propose, seems less promising).

A differentiation in marketing strategies is proposed:

- *make the low eco-costs of a product a competitive edge for commodity products (products where it is hard to differentiate on price/value), but keep the price/value at the same level*
- *make the low eco- costs part of the image for specialty products and high quality products, but do not stress the sustainability issues too much, since consumers go for the best price/value.*

It is shown why it is so difficult for governments to force the industry in the direction of sustainability, and keep a level competitive playing field at the same time. Gradually increasing tax on pollution would work in a closed economy, but has the adverse effect of 'exporting environmental pollution' in an open, global, trade. Tradable Emission Rights systems for the industry, in which the government takes part, seem to be the most promising solution on national level. On a global level a Tradable Emission Rights system between governments might be the right tool to freeze the CO_2 emissions to its current level. On a global level, drastic and fast reduction of the emissions, however, cannot be expected. The goal can only be reached step by step.

Systems of subsidies (or tax relief) on consumer products are suitable to facilitate the market introductions of innovative products, but only in market niches, and only for products with a high EVR. General subsidies (or tax relief) for other than these products have to be avoided.

9.1 Introduction.

At the end of this thesis the question arises as to what conclusions can be drawn from the EVR model in terms of decisions which ought to be taken by business managers and governmental authorities (and political parties) to support the further transition of our society towards sustainability.

The role of the designer of products and services is relatively straight forward: the EVR has to be made as low as possible, as described in Section 5. However, the road towards sustainability is much more complex than just creating products and services with a low EVR for the supply side of our economy. There has to be a demand for such products as well, e.g. consumers have to buy them, otherwise there will be no de-linking of the economy and the ecology.

In general, individuals are neither prepared to pay more for 'green' products, nor are they prepared to give up their 'freedom' in terms of less travelling. However, people (in The Netherlands) are quite aware of the importance of the issue of sustainability, and are aware of their responsibility in this respect[40] (Steg, 1999). The question is now: what has to be done about it? The fact that people are positive about the issue

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[40] *A Dutch enquiry (1995) on the subject revealed a surprisingly high score on the question: "people behave irresponsibly when they do not take environmental effects into account". The average score was 4.3 on a scale of 1 (totally disagree) to 5 (totally agree).*

of sustainability has to be converted to a situation where people buy sustainable products, but how?

The environmentalists in The Netherlands seem to be more and more disappointed that the market shares for 'green' products stay marginal (2 – 6 %), irrespective of the many efforts which have been taken in the recent past (Hoefnagel et al., 1996) (Steg, 1999) (Nas, 2000) (CBS, 2000). The question is, however, whether the right measures have been taken up to now.

In this respect it is important to realise that (Senge, 1990):
1. the required transition is rather a process than quick fix
2. the system to be changed is rather characterized by complex circular interrelationships than by simple linear cause-effect relationships
3. the harder environmentalists push, the harder the existing system will push back
4. small changes in the dynamic system can produce big results – but the areas of highest leverage are often the least obvious.

To analyse the problem (or rather: the opportunity), some new approaches are proposed in this Section, beginning with a system description of the interaction between the 3 main stakeholders: the consumers/citizens, the government(s) and the companies. This interaction is summarized in the 'three stakeholders model'.

9.2 The three stakeholders model.

In the transition towards sustainability, each of the stakeholders have to play its own role:
- the consumers/citizens have to shift their expenditures towards a lower Eco-cost / Value Ratio, i.e they should buy 'green' products and services
- the companies have to create product-service combinations with a lower Eco-costs / Value Ratio, i.e. they should offer 'green' solutions to the market
- the governments have to create regulations and new systems for tax, subsidies and Tradable Emission Rights, i.e. they should create a business environment which gives 'green' solutions a fair chance in competition with the current products and services.

It is obvious that, when one of the stakeholders fails to play the right role, the transition towards sustainability will not happen. What triggers each of the stakeholders of the system to go in the right direction? Who triggers the transition process? Designers tend to believe in 'technology push': when the green products are on the market, they will be bought in the long run, but the reality seems different. The general business opinion is inclined to 'market pull': the consumers have to trigger off the demand. Why should they do so? In reality they tend to go for the best price/value proposition in the market instead of the proposition with the lowest environmental burden, since the latter is normally slightly more expensive. Advertising campaigns to make people buy the slightly more expensive 'green' option failed to succeed so far.

Apparently, the government should do something as well: level the playing ground in the market, i.e. create a system in which the 'green' solutions have a fair chance.

The key to the solution of the problem is to realise that the consumer is an individualist, reacting instantly and in the short term to offerings on the market. Sustainability, however, is a long term issue for the citizen. We have to realise that each individual is consumer as well as citizen.

The interactions of the consumer/citizen with companies and governments are depicted in the three stakeholders model[41] of Figure 9.1.
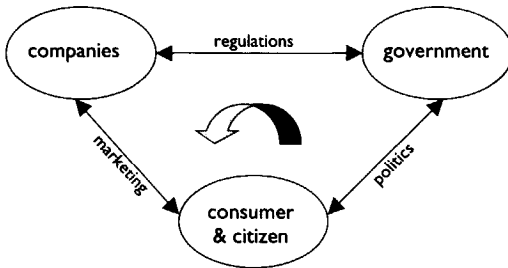
Fig. 9.1: The 3 stakeholders and their main interactions.

The three stakeholders have 3 different interactions with each other:
- the citizens are interacting with their governments via politics: citizens want to have a sustainable future, are aware of the fact that the required transition can only succeed when we put our shoulders under it *together*, and therefore ask the government to take action
- the government is interacting with the companies: governments take actions via regulations, taxes, subsidies, 'convenants', etc., and force companies to react
- companies are interacting with consumers: companies try to offer consumers 'best value for money' and gain market share by satisfying the (short term) customer (individual) needs.

The predominant direction to trigger the required transitions in the circle of Figure 9.1 is counter clockwise, as described above. In some business areas, industry is acting pro-actively (instead of reactively), for instance in the automotive industry. In those areas, one is trying to gain a competitive edge by being the first to meet future governmental standards, but the underlying reasoning of those business strategies is counter clockwise in terms of the three stakeholders model of Figure 9.1.

Initiatives which start with the consumer business relationship (the clockwise direction) tend to remain limited to the small market niche of people (2%-6%) who regard the environmental aspects of products as more important than the price/value ratio.

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[41] *The validity of the model was checked in three computer decision room sessions with consumers, business representatives and governmental representatives. See Section 8 and also the questionnaire of Table 8.4.*

It seems extremely difficult to extend these markets to the 'normal' markets of price/value buyers[42]. There might be a few exceptions though in the near future, where the transition towards bigger markets for 'green' (or 'greener') products are driven by new marketing concepts only, without the direct support or intervention by governments. A most promising example is the business of the supply of 'green' electricity in the consumer markets, triggered by the internet in combination with the new opportunities in the evolving free electricity markets (Green Mountain Energy Company, USA). Chapter 9.3 and 9.4 will deal with product portfolio strategies and marketing concepts which support such business initiatives.

9.3 Product portfolio strategies of companies.

A major strategic question for companies is: "Do we have the right portfolio of products (and services) for the future?". Aspects are:
- can products be improved?
- have services to be added?
- can the customer needs be fulfilled in a fundamental other (= better) way?
- is it a viable business (market) for the future?

Pro-active companies will not be surprised by governmental regulations or green tax, but will have directed their business (products, production processes, services, consumer markets) well in advance. The virtual eco-costs as a single indicator for environmental burden has been developed as a yardstick for imminent business problems in the field of sustainability. From the business point of view, the 3 main components of the eco-costs have to be interpreted as follows:
- the pollution prevention costs is an indicator for the extra costs of a product or service which could be expected in the long term when a company does not reduce its emissions, since it is a current best guess for the ultimate level of green tax or tradable emissions rights (a 'what if' analysis of the current situation with regard to a sustainable sate of emissions); see also Section 2
- the eco-costs of energy are an indicator for the costs of energy in the long term (current prices), since the level of eco-costs is based on the costs of a range of renewable energy systems which are required to reduce the CO_2 emissions by, at least, a factor 2
- the eco-costs of materials depletion indicate that there might be a future problem with regard to materials (this indicator is a norm for the degree of recycling rather than a predictor of future prices).

Products with a high level of eco-costs (in comparison with their value) have the problem that their costs might increase sharply in the future, see Annex 9a, caused by

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[42] *In some exceptional situations, pressure groups have been able to trigger consumer boycotting actions, which forced companies to shift their environmental policy (Brent Spar; some products of Sainsbury). This can happen only under special conditions (Hall, 2000), and therefore cannot be regarded as the standard road towards sustainability.*

measures taken by governments. The costs of a product might even rise above the level of its value to customers (then there is no market for that product). So it makes sense to take action in advance.

To analyse the short term and the long term market prospects of a product or product service combination (Product Service System, PSS), each PPS can be positioned in the portfolio matrix of Figure 9.2
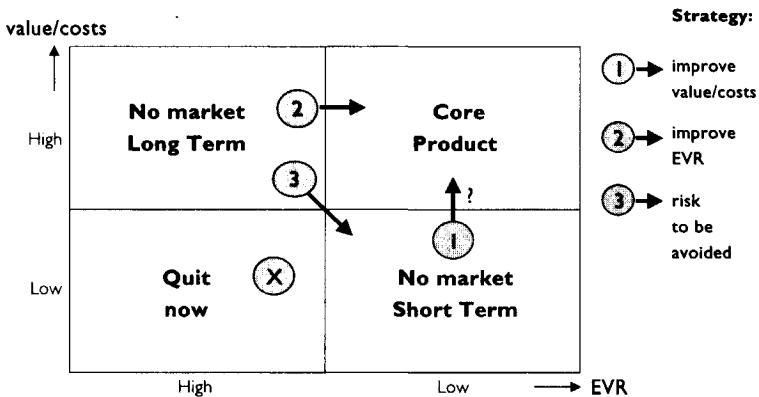
Fig 9.2: Product portfolio matrix for product strategy of companies.

The basic idea of the product portfolio matrix is the fact that a product or PSS is characterized by:
-   its short term market potential: the value/costs ratio
-   its long term market requirement: the EVR.

In terms of product strategy, the matrix results in 4 strategic directions:
1. enhance the value costs ratio of a sustainable design with a sound EVR to make it fit for short term introduction on the market
2. enhance the EVR of current successful products to make it fit for future markets
3. be careful that direction 2 does not result in a lower value costs ratio
4. abandon products with a low value/ costs ratio and a high EVR as well.

For a 'sustainable product', the usual problem is that it has a low current value/costs ratio (in most of the cases the production costs are higher than the production costs of the classic solution). Usually, this can be related to two causes or a combination of both;
-   there is no market volume for the sustainable solution, and therefore no 'economies of scale'
-   the classic solution has lower costs since higher levels of pollution are tolerated.
Such a situation is not easy to tackle, and the adverse business attitude of most of the environmentalists does not create an atmosphere to resolve such a complex market

introduction problem. When the government sets limits to the environmental pollution or introduces green tax or tradable emission rights, part of the problem will be solved (the playing field is levelled), but the economies of scale problem is still there. The best solution is then to integrate the new sustainable product in production and distribution systems of the classic products to eliminate the economies of scale problems. Currently the cultural differences between environmentalists and business managers are often a serious hurdle for such an integration.

For a product which has a good present value/costs ratio, but a high EVR, the product and the production process have to be redesigned to enhance the EVR (lowering the eco-costs). One may also think about other ways of satisfying the needs of the customers by alternative product-service combinations. This road towards sustainability is far more promising than the first strategy. The reason is that the economies of scale for production and distribution are available and that the new product is marketed to an existing client base which is used to the brand name, the quality standards, the service system, etc. The most common fear of business managers is that their new products end up with a deteriorated value/costs ratio, and hence will have a cumbersome position in the market. The stability of the governmental policy plays an important role here. When governmental regulations which level the playing field are postponed or even abandoned, proactive companies with sound product strategies are harmed. This can cause severe damage to the transition process and may lead to reluctance of players to move proactivily in the future.

9.4 Consumer marketing

9.4.1 The Double Filter Model

Consumers select the 'quality products' they buy on the basis of a comparison of the perceived value of these products. Within a certain price range they seek for the best value for money, where value can be defined as the fair price, see Annex 5b. Consumers select the 'commodity products'(products which cannot be differentiated by quality or design) on the basis of the lowest price.

As it has been mentioned in the introduction, the vast majority of the consumers (94%-98%) are not prepared to pay more for 'green' products, and 'green' products are generally slightly more expensive. In other words: the consumers are not valuing the environmental aspects of products in terms of a higher 'fair price', despite many efforts (awareness campaigns of environmentalists).

At the same time, the level of the environmental awareness in The Netherlands is quite high: 89% agrees with the statement: "environmental pollution is a severe threat for our children" (Aarts et al., 1995). The Dutch seem even to agree on their individual responsibility in this respect, see Note 40. The big issue is therefore why there is such a big difference between the environmental awareness and the behaviour of people as consumers ("consumers are short term individualists"). It seems that people

feel that the environmental problems can only be resolved by a joint effort (Nas, 2000), and that individual behaviour is quite useless, *unless it is agreed (and arranged by the government) that everybody has to do it.* The Dutch proverb: "change the world, start with yourself ", seems to be replaced by: "the government has to set and keep the rules". In the 3 computer decision room sessions as described in Section 8, it appeared that the decision process to rank products in terms of personal preferences was slightly more complex than just deciding on the basis of the best value for money. Environmental aspects played a secondary role ("the Double Filter Model") as depicted in Figure 9.3.

1st Filter: 2nd Filter:
quality and price?   environmentally OK?
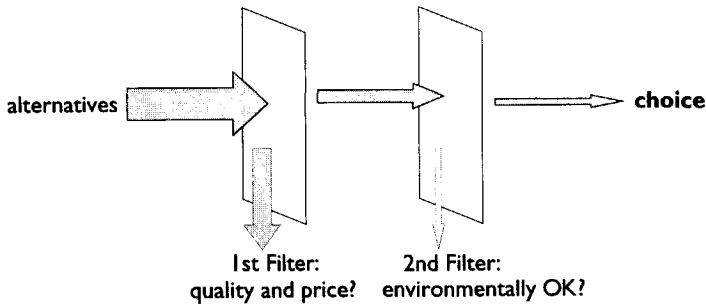
Fig 9.3: The Double Filter Model: environmental data serve only as a second order filter in the decision of consumers.

Nearly all participants of the 3 computer decision room sessions appeared to make their first choice on the basis of value for money. However, when a decision could not be made on this first criterion, the environmental data were used to make a final choice.
Apparently people make their choice first as consumer ('short term individualist'), but when that does not lead to a clear decision, they add considerations as a citizen (long term, including considerations for the society).
The next chapter will deal with the consequences for marketing of 'commodity products', which compete on price, and specialty products which differentiate by quality and design ('quality products').

9.4.2 Marketing of commodity products and quality products

Although environmental aspects seem to be a secondary criterion for the choice of consumers, it can have an enormous impact in the marketing and sales of products and services, since a high percentage of consumers care about the environment in their role as citizen.

Especially for commodity products (water, electricity, food ingredients, but also electronic appliances like video recorders and services like travel by plane), where price is the predominant selection criterion for the market segment, the environmental

aspects might become the competitive edge. Green Mountain Energy Company in the USA is one of the first companies in the world that realises that there is an enormous potential for 'green' electricity in a free and open energy market for consumers, *because it is hard to differentiate such a product (all electricity is equal).* Their marketing studies in the USA show that 50% of the households are interested in green electricity. They estimate that 10 % - 20% of these households is prepared to buy green electricity, even when the price is slightly higher. This Texas based company is already marketing their product in California, Pennsylvania and New Jersey where the electricity markets have been liberalized. Their approach is pure marketing driven in the modern way, appealing to the 'feel good' factor which is quite important in our current society. Annex 9b gives an impression of their price policy and the way they advertise[43].

The basic idea of marketing green commodity products is depicted in Figure 9.4. Take as an example a video recorder (mono and 'show view'). The price in European discount shops is about 250 Euro, plus or minus 10%. They are all black, have the same shape and look. The choice is typically between 4 to 6 manufacturers (Sony, Philips, Panasonic, etc.) which are available on the shelf. Many people do not know which one to choose, and follow the advice of the salesman in the shop. In those cases there is an opportunity for a secondary selection criterion: the environmental aspect. Under the condition that the environmental burden of the alternatives is known (in terms of eco-costs or any other single indicator or equivalency), and under the condition that this is communicated in the right way, there is a high probability that the consumer will buy the greenest video recorder. Green Mountain Energy Company is marketing their product along the same lines of reasoning: differences in price are negligible (5 – 15 Euro per month for a household), they offer a choice from three well explained solutions, and appeal to the 'feel good' emotions of 'reconciliation of the consumer and the citizen' within in each person.
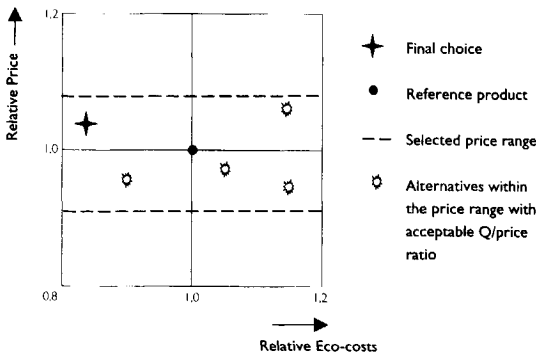
Fig. 9.4: Eco-costs as a competitive edge in the marketing of a commodity product.

[43] The Dutch electricity distributor NUON bought 23 % shares of Green Mountain in October 2000, and started a similar marketing approach for Dutch households as of December 2000.

The consequence for the product portfolio management of such a marketing approach is that new environmental products have to fall within the normal price range. It is better to offer a good green solution within the price range, and sell many of them, than to go to the extreme and discover that there is no market for it. See also the product portfolio management strategy of Figure 9.2. The relevance of this marketing approach (and consumer behaviour) is not only that a small environmental gain which is applied many times is more effective than a big gain which fails the acceptance in the market, but also that every manufacturer will try to become the best in terms of sustainability. This will lead to a fierce competition on this issue. Such a competition might become a major drive for the de-linking of economy and ecology.

For quality products, the situation is more complex. Firstly, it appeared in the 3 computer decision room sessions that the fact whether or not a product is green, can suddenly become the decisive factor in the final choice. This is the case when two (completely) different solutions for the same functionality are perceived as equal in terms of value for money. In such cases, the situation is comparable with the situation for commodity products and Figure 9.3 and 9.4 can be applied. Secondly, it cannot be denied that, for products in the high quality range, the issue of sustainability can be made part of the product image (example: Swedish cars in comparison with American cars). The 'feel good' factor is extremely important for the 'high end' markets. It seems that the environmental issues have to be bundled with other societal issues (safety, health, conservation of nature and cultural heritage; in other words future welfare for our children). In this respect it is good to realise that sustainability is in the top 5 of the Dutch societal issues for 3 decades. A distinctive focus on the environment seems not to be a recommendable strategy: people with higher education (in The Netherlands) seem to be irritated by the extreme standpoints of environmental action groups (Nas, 2000). A careful, positive, marketing approach is required for the 'high end' products to enhance the market share. Pushing too hard with moral statements will have an adverse effect and will hinder a gradual transition towards sustainability in consumers markets.

9.5 Governmental policies for sustainability

9.5.1 The problem

With regard to the environment, the major task of the government is to facilitate (and enforce) the transition towards a sustainable society for their citizens. In the light of the three stakeholders model, the role of the governments is to create regulations and new systems for tax and subsidies, in order to to create a business environment which gives 'green' solutions a fair chance in competition with the current product and services.

There are 3 important aspects with regard to governmental regulations and systems for tax and/or subsidies:
1. the commercial playing fields have to be kept level during the transition period,

ensuring that a company cannot gain position by avoiding investments and innovations

2. regulations have to cope with the fact that governments can only set rules within their own territory, whereas world trade has no longer any restrictions (according to regulations within the EU, and agreements of the WTO, protection of own industries has been forbidden)

3. regulations have to stimulate innovation within the life cycle.

With regard to point 3 it is important that the transition towards sustainability will trigger innovation, which will make the transition less costly than many believe it will be. Innovations are supported by regulations in which (Porter et al., 1995):

- results are regulated, not technologies (leaving maximum room for "how" the results are achieved)
- strict requirements are set to results (leaving no room for half solutions)
- rules are set at the end of the chain (leaving maximum room where and how to make changes in the chain)
- free market initiatives are encouraged (to create new combinations of activities, new 'profit pools')
- phase-in periods are defined and adhered to (innovation takes time and requires stable governmental policies).

The major problem of governmental regulations is how to combine point 1 and point 2 in an open economy. This major problem can be explained by describing the dilemmas of a few scenarios for governmental policies, analysing the effects of these scenarios by means of Figure 9.5.
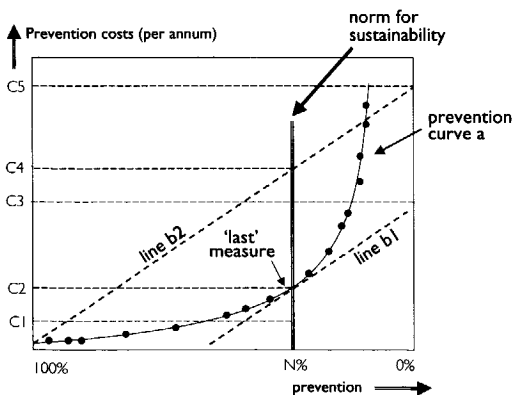
Fig. 9.5: Marginal prevention costs and total costs on the road towards sustainability.

The basics of Figure 9.5 have already been explained in Annex 2a for the case of emissions: For each type of emission, the costs and the effects (in terms of less emissions) are accumulated for several prevention measures to be taken (a 'what if' calculation), the 'prevention curve'. At a certain point of the curve, the 'norm for sustain-

ability' is reached. The marginal prevention costs are defined by the costs per kg reduction of the 'last' measure, depicted as the slope of line b1.

The basic problem is not that the total costs to reach the norm for sustainability are too high. For acidification + eutrophication + summer smog + winter smog + heavy metals, the total Dutch prevention costs per annum, C2, of the curves as calculated in Section 2 are approximately 2.5 billion Euro, being only about 0.7% of the Dutch Gross National Product (GNP). The annual costs of prevention measures for CO_2, as proposed in Section 2, are estimated at 2.3 billion Euro (including savings of energy consumption), being approx. 0.6% of the Dutch GNP [44]. The problem is though to distribute the costs of those measures: who pays what? Since those measures are distributed over all sectors of our economy, and since the price of each measure is different in terms of Euro/kg, it is not feasible to 'dictate and specify' technical measures to all parties involved. So what to do in terms of regulations to lead the market towards sustainability? Taxation? Tradable emission rights? Subsidies?

The problem will be analysed by separate scenarios for tax, tradable emission rights, and subsidies.

9.5.2 Taxation

The simplest way of pushing every party involved towards sustainability is taxation: suppose that emissions are taxed at the level of the marginal prevention costs (Euro/kg) at the norm for sustainability (this costs level is depicted in Figure 9.5 as the slope of line b1). The result will be that all parties will take prevention measures rather than pay tax, if these measures are at the left side of the norm for sustainability in Figure 9.5. Parties at the right side of the norm will prefer to pay the tax, since the measures are more expensive. So taxation is effective and simple in terms of pushing all parties involved in the right direction.

The disadvantage of such a sudden, simple taxation system is that the total sum of tax for emissions is exorbitantly high at the start of the transition: see point C5 in Figure 9.5. This high tax level will be rather devastating for our economy, so citizens are not likely to make such a heavy sacrifice for sustainability. After the prevention measures have been taken, the total costs of measures + tax will become lower: point C3 in Figure 9.5.

Increasing the tax in small increments over a long period of time will resolve the problem of the wild disruption of our economy (point C5), but the end result will be that the sum of measures + tax is still rather high (point C3). Especially in an open economy high costs levels for emissions are problematic in terms of the international trade: products become too expensive to stay competitive and there is a big likeli-

[44] *The required extra investments in prevention measures for acidification + eutrophication + summer smog + winter smog + heavy metals are estimated at 25 - 30 billion Euro. The required investments in prevention measures for CO_2 are estimated at approx. 20 billion Euro (Beeldman et al., 1998).*

hood that production will be moved outside the borders ('export' of environmental pollution).

One can conclude that tax may be effective from the point of view of reduction of pollution within a country, but is not advisable from an economic point of view. It has a much bigger influence on the economy than seems to be required: the method seems to be to coarse (the tax which is paid at the right side of the norm in Figure 9.4 does not serve any purpose).

9.5.3 Tradable Emission Rights

Systems for Tradable Emission Rights (TER) are much more subtle that tax systems. Those systems support the flow of money to investments on the most cost effective prevention measures in the industry (Sorrell et al., 1999) TER systems can only be applied in combination with rules which restrict 'free' emissions of production plants.

The first scenario is the most pure form of TER:
- free emission rights of production plants are restricted to the current emission levels (so the current level of emissions are the maximum free emission rights for the future)
- companies are allowed to buy emission rights from other companies.

The result of such a system is twofold:
- companies which expand, have to buy emission rights from other companies to extend their allowable emission levels
- companies which have the opportunity to reduce their emissions by prevention measures, will do so when they can sell their emission rights at a higher price than their own investments required for prevention.

In such a system the market will take care of an optimal distribution of prevention measures in terms of cost effectiveness.

When total emission levels have to be reduced, the situation becomes slightly more complex. Emission reductions of 10%, 20% or 30% will work basically in the same way along the lines of the aforementioned scenario. The reductions have to be implemented gradually (in small steps and slowly) to avoid heavy disruptions to the TER prices[45]. Reduction of a factor 3 or 4, as depicted in Figure 9.5, can better be implemented when the government takes part in the trading system. The first scenario has then to be replaced by another scenario, which is summarized hereafter.

This second scenario is then as follows:
- the government sets free emission levels to $1/3$ or $1/4$ of the current level (these TERs are given at no costs)

[45] The dynamic behaviour of such a "volume controlled" system results unstable prices because of the lead time of the prevention measures (control loops with a lead time are inherently unstable).

- the government sells the additional TERs at a levy per annum at the price level of x% of the marginal prevention costs per annum; x is slowly increased, step by step, until 100% is reached[46]
- companies can give the TERs back to the government (to avoid the annual the levy), which they are inclined to do when their own prevention measures (in terms of costs per annum) are less expensive
- companies can sell TERs to other companies as well (at a price level of the annual levy, or, at a slightly higher price per annum).

The advantage of such a scenario is:
- the burden of the levies is gradually increasing, investments to avoid the levy can be carefully scheduled
- companies are free to expand their activities, at the cost, however, of the price of the TERs they can buy from other companies
- the total burden at the moment of introduction can stay rather low, for instance at the level of C1 (lower than the total prevention costs, C2, to minimize the economic disruption at the start)
- the total burden will rise to a maximum level of C2 at the end of the transition.

Note that governments might compensate the levies at the beginning of the transformation with a tax relief (shift the burden of tax), as long as international agreements against protection of national industries are not violated.
Note also that the basic problem of introducing TER systems is the assessment of the level of applied technologies in current industries: companies which already did a lot in the field of emission prevention should not be 'punished' at the introduction by getting the emission rights at the same price as companies which did nothing in the past. At the moment of introduction, the emission level per output quantity and the 'distance' to BAT has to be brought into the equation.

An important advantage of TER systems is that these systems relate the environmental measures to the direct product costs in a way which is clear to all stakeholders (eco-costs become real costs in a direct and understandable way). When the TER costs in a product are directly communicated to consumers, consumers with a high level of environmental awareness are able to avoid products with a high level of TER costs (resulting in a shift towards a lower EVR).

9.5.4 Subsidies

Subsidies are not suitable for industry: they disturb the inherent competitiveness of companies and they are normally violating regulations of international trade systems (it protects the national industry). On the other hand, subsidies are suitable on the level of households. Here they can be applied as well in the form of tax relief.

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[46] *Note that, when the TERs are introduced at the level of the marginal prevention costs at the norm, this would lead to a costs burden C4 at the moment of introduction.*

The aim of subsidies is to influence the expenditures, especially on investments. Subsidies have to be applied with great care:
- subsidies have to be specific for market niches (see the example of the TV of Section 3)
- the rebound effect has to be taken into account (generally speaking, subsidies can only be applied for products with a high EVR, see Section 5).

Subsidies are the ideal tool to support market introductions of innovation: the new sustainable solution can be made less expensive for the consumer than the classic product (for the period of the learning curve and the economies of scale curve).
A good example of tax relief on products was the introduction of the catalyst gas exhaust pipe of cars. It is likely that innovative motor designs like the fuel cell motor need to be supported by subsidies as well to bridge the first production period with a low 'economies of scale'. Innovation of fuels for cars (like ethanol from biomass) might also be supported by tax relief systems (as has been done in the past for lead free gasoline).

9.6 Discussion

9.6.1 The 'three stakeholders model' in the building industry

In some markets, like the building industry, the real world is much more complex than it is described in the three stakeholders model. See Figure 9.6.
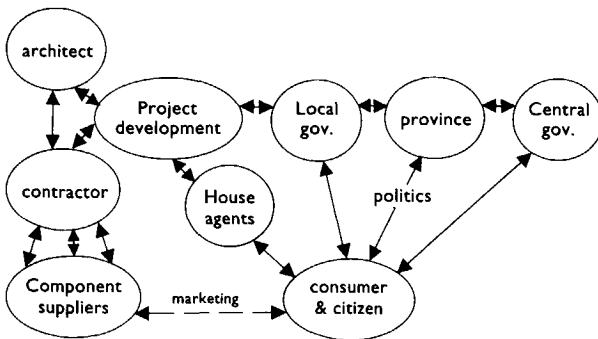
Fig 9.6: The interaction between consumer/citizen, government and industry in the building market.

It is obvious that, in such a complex market as the building industry, the transition towards sustainability can only be driven by strict and detailed governmental regulations:
- the planning process at the governmental side is rather complex, so the interaction with citizens is blurred
- the industry is organized in a rather complex way, which is not transparent for the consumer.

Recent attempts (by the Dutch company NBM Amstelland) to make the industry more transparent for the consumer by internet seems promising: consumers are offered better information and more influence throughout the building process. This might support the transition to sustainability.

9.6.2 Consumer marketing, beyond 'green products'

In chapter 9.4.2, the marketing of 'green products'[47] has been dealt with. The focus of marketing of green products is the fact that they cause less material depletion, they have been produced in a cleaner way, that they require less energy in the use phase, and/or that they can be better recycled. These characteristics should be communicated in the right way, being aware of the Double Filter Model.
In line with this way of thinking is that a product might be replaced by another system which fulfils the same functionality.

Beyond this way of dealing with the required transition, there is an opportunity which might have a much stronger impact on sustainability. This opportunity is related to enhancing the value of products, accompanied by the marketing of this value. In the extreme case, the value might be built on marketing only: enhancing the image of products and services. The idea behind this is that, from macroeconomic point of view, the Gross National Product of a country can be calculated in 3 ways:
- analysing the production within a country
- analysing the total income within a country
- analysing the total expenditures within a country.

In a steady state, total production (including services), total income and total expenditures are equal. The classical approach of the majority of the environmentalists is to try to lower the environmental burdens of the production side. Most of the environmentalists agree on the fact that it has also to do with consumer behaviour (as mentioned in Chapter 9.1), but solutions seem to be restricted to "consumers should consume less" (easy to say but hard to accomplish). In this paradigm, marketing (advertising), is boosting consumption. Therefore marketing is one of the root causes of environmental problems.

It is good to realise here that marketing as such does not boost our personal expenditures: generally people spend during their lives what they earn[48]. It is not likely that, without marketing, the savings (excluding savings in pension funds) would have been above 20% of the available income.
Marketing, however, has a major influence upon what we spend our money. A general shift from products with a high EVR towards products and services with a low EVR can have an enormous impact in terms of environmental pollution. This aspect has

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[47] *'Green products' are characterized by the fact that the co-costs of the total life cycle are lower than the eco-costs of the classical products with the same functionality.*

[48] *In The Netherlands, during the period 1990 – 1996, the value of 'expenditures of households' varied between 93% to 99% of the value of 'available income of households' (after tax).*

already been dealt with in Section 5[49]. In general, a positive impact on our environment of a factor 4 or more (in terms of EVR) can be expected when consumers shift their expenditures from cheap products to luxury product-service combinations. The more image, the higher the EVR and therefore the better for sustainability!

The conclusion is that enhancement of the value of a product-service combination has a very important effect with regard to the required transition towards sustainability. The fact that business managers often try to enhance the value of their products for better profitability only (the short term benefits are the driving force, not the long term benefits like sustainability) might be disputed in the moral sense. However, the practical implications in terms of sustainability are of such an importance that environmentalists should become less adverse about marketing issues like 'perceived value', 'image' and luxury products in general.

9.6.3 Governmental policies

On the level of the government, the same principles apply as have been described in the previous chapter: there are much more opportunities than only cleaner production.

Cleaner production is a very powerful instrument on the road towards sustainability (VROM, 1996a and 1996b). The conclusion may be drawn from chapter 9.5 and Section 2 that the norm for sustainability is within reach:
- the technical measures are available in terms of BAT (best available technology)
- the measures are financially feasible
- the government can design 'instruments' to facilitate the transition.
the only thing which is still required is the political will, but that seems to be a matter of time.

More might be done, however. It remains to be seen whether or not it is wise to keep all types of exporting industries with a low EVR within The Netherlands. A stop on the many forms of subsidy and tax relief in those sectors seems to be in line with strategic logic, but the political will to do so is not yet in view. In fact, the product portfolio matrix for company strategy of Figure 9.2 can also be applied on the national level for the several industrial sectors. Policy making on national level would certainly benefit from a proper strategy on a 'national industrial sector portfolio matrix', with regard to the subject of sustainability[50].

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[49] *The underlying assumption is that, in general, the consumer price in a free market tends to be near the consumer value. When consumers shift their expenditures towards products and services with a low EVR, the total eco-costs related to their expenditures will decrease.*

[50] *On a regional scale, the industry as well as the government could benefit from a coherent combination of industrial activities (industry clusters), see (Hafkamp, 1998).*

9.6.4 International trade in CO_2 emissions

At the international discussions on how to reduce CO_2 emissions, the approach of
some countries (e.g. the USA) to take measures in other countries, triggers heavy
moral debates. However, the introduction of TER systems at the level of governments
seems to be a practical solution to tackle (part of) the problem of the ever increasing
emissions. Such an international TER system can only be of the type of the first sce-
nario of Chapter 9.5.3. Unfortunately, as already been mentioned, such a scenario is,
in the first instance, only applicable to a *standstill* of emissions, not a *reduction* of
emissions. However, a standstill can be a first practical step forward in the current sit-
uation. Once the TER system is established, a step by step reduction programme can
be implemented.

Such a TER system needs to be based on the following rules:
- trading of emission rights can only be done between countries which stick to their
  maximum basic emission levels
- the money of the rich countries which buy emission rights, has to be spent on real
  technical measures to reduce emission levels in poor countries (the extra emis-
  sions in the rich countries have really to be compensated by less emissions in the
  poor countries): emission reductions in poor countries caused by economic reces-
  sions are not tradable.

In such a TER system, technology and money is transferred from the rich to the poor
countries. It is based on enhancing the energy efficiency in the poor countries, from
which their economies will benefit as well. It seems to be a first step in the direction
of what is called the 'new era of economic growth', see Annex 1a. At the same time
it seems to be a direction which is outside the paradigm of the majority of the envi-
ronmentalists ('stand still is not enough'; 'rich countries should resolve their own
problems'; 'nothing good can be expected from global trading systems'; 'economic
growth should be stopped').

9.7 Conclusions

The combined approach of eco-costs and value reveals new opportunities to reach
"the factor 4" or even higher. The required transformation , however, is far from easy:
- the three stakeholders have to act together: the mechanisms which are required,
  all need an integral approach (interactions between only two of the three stake-
  holders cannot succeed)
- the two sides of the human being ('the citizen' and 'the consumer') need to be
  reconciled (brought into equilibrium) and a political will has to be developed.

In terms of communication, a shift of focus is required: from 'awareness of the immi-
nent threats' (negative feelings) towards 'understanding of solutions' (positive feel-
ings). The marketing aspects of green products are totally new. Marketing in this field
is still to be developed (by professional marketeers and not by environmentalists!).

Lessons can be learned by pioneers like Green Mountain Energy Company (what will work, what not ?).

Further development of Tradable Emission Right systems is required to decrease industrial pollution, and further analyses are needed in the field of the rebound effect to design subsidy systems for market niches:

"Planning of the road towards sustainability requires the so called 'out of the box' type of thinking."

10. Conclusions and recommendations

Further research and activities for diffusion of the model

Abstract

This Section deals with the questions: what is achieved and what next?

This final Section is not meant to discuss the details of the model. Such discussions were held, if applicable, at the end of each of the previous Sections.
This Section, however, is about two main issues:
- *with regard to the research questions of this thesis as given in Chapter 1.4, the main issue is how the work, after completion of this research, might be extended (recommended further studies on the model)*
- *with regard to further application of the model, the main issue is what is to be done to get the model widely accepted and applied in practice (recommended steps for diffusion of the model.*

10.1 Recommended further studies on the EVR model

The research tasks of this thesis were (as stated in Chapter 1.4):
1. develop a single indicator for toxic emissions, (if possible to be monetarized, and later to be expanded to use of energy, and materials depletion)
2. develop an indicator for 'eco-efficiency'
3. enhance the allocation methods in the current LCA methodology to cope with the allocation problems in calculations of services
4. make a new model for the End of Life stage of complex products (like buildings)
5. define consequences of the new model for 'eco-efficiency' for design and business strategies, check with cases
6. apply the EVR model on one complex service system, being a transport case (related to the strategic dilemma of the manufacturer of transport packaging as mentioned in the preface)
7. develop a single indicator for land-use
8. establish the hurdles in communication of environmental issues and relate them to the new model
9. define the consequences for companies and governments.

The question is now: after completion of this work, are there new areas of research evolving from this study? For the discussion on this matter, the research questions are grouped:

A. the model (points 1, 2, 3, 4, 7)
B. the application of the model as a design tool (point 5, 6)
C. the application of the model as a decision support tool (point 9)
D. the diffusion of the model (point 8).

A. The model

We have to distinguish between three different aspects of the model:
- the model itself (i.e. the methodology)
- the data which are used in the model (i.e. the data to calculate the eco-costs)
- the application of the model and its data in specific cases (the 'operationalization').

With regard to the model itself, one of the main discussions is whether more issues (characterization systems) should be added or not. This discussion was triggered right from the start of the research and was made explicit in the first publication (Chapter 2.7.3) and in the Call For Comments of this publication (question 2, Annex 2b). The recommendation is to keep the model restricted to the 3 classical sustainability issues of materials depletion, energy consumption and toxic emissions. The current trend (e.g. in SETAC) to incorporate all sorts of other issues (like health & safety), will lead to a situation where the LCA methodology gets blurred in its applications (see also Chapter 2.7.3).

The fact that the issue of land-use (and noise) was added in a later stage to the model was related to the fact that the model might be used as well for environmental assess-ment of urban and rural planning (the Dutch "Milieu Effect Rapportage"). For this pur-pose, two new areas for further research might be considered:
- characterization systems and the marginal prevention costs for noise and for smell[51]
- a characterization system and the marginal prevention costs for fauna[52].

With regard to the data the eco-costs are based on, there are three issues:
- the Dutch data to calculate the marginal prevention costs of emissions are from the period 1990 – 1992, so it is time to update these calculations (this was already

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[51] *Note that the relationship between 'emissions' and 'immisions' (as perceived by the people involved!) is very complex for these issues, where time and place play a dominant role and where calculations are of a non-linear character. Annex 10 provides a first attempt to determine the eco-costs of noise for specific sources of noise (a car and a road), and shows its methodological limitations.*

[52] *With regard to this issue, two recent developments should be mentioned:*
- the evaluation system for rare, endangered and internationally important species (Strijker et al., 2000), based on data of IKC Natuurbeheer for the Netherlands (areas of 25 km²)
- a characterization system for butterflies in The Netherlands (Bleij et al., 1998), where the methodology of Witte (Witte, 1998) was applied.

a remark in (Dellink et al., 1997))
- data for other countries on the marginal prevention costs of CO_2 are partly available (Sorrell et al., 1999), however, for the other emission classes these data seem hardly available[53]
- a lot of LCA data are from 1990-1995, and are based on outdated industrial averages; there is a need for more recent data on industrial averages as well as data on Best Available Technologies[54].

With regard to the application of eco-costs in LCAs (the "operationalization"), the availability of LCA data is the most important issue. It is a pity that many of the Dutch LCA databases are not freely assessable (they are exploited commercially) which inhibits the creation of one, integrated and generally accepted, set of data.

B. The application of the model as a design tool (point 4)

Basically, the application of the model as a design tool appeared to be successful: in all cases so far, it was possible to apply the methodology, and in all cases the application of the model has lead to a better understanding of the case in terms of sustainability. Especially the two dimensional approach (eco-costs and value) revealed a new understanding of problems and their solutions. The Ecoscan computer software appeared to be very user friendly, and the EVR database (compiled from all data of Sections 2, 3, 4 and 6) was sufficient to make the calculations for all cases.

The main concern, however, is that environmentalists and designers, in general, seem to have little knowledge on the issues of price, value, added value and the value chain. Also the expertise on how to gather data on costs (and prices) seems to be lacking (to cope with this problem is a matter of appropriate diffusion of the model, which will be dealt with in Chapter 10.2). The Delft University of Technology should pay more attention this lack of indispensable knowledge.

With regard to operationalization of the model in the building industry, a research programme is under development (resulting in a PhD thesis) to extend an existing cost-calculation database for architects and construction companies, Winket, with an eco-costs database. The key of this research programme is to develop a modular system of building components which makes the conversion from costs to eco-costs feasible (a computer calculation program based on characteristic EVR data).
The resulting database of eco-costs for the building industry will be integrated in the commercially available Kubus Kalk cost-calculation software. The result is a tool for

[53] *The methodology seems to be quite well accepted, since there were neither negative reactions, nor proposals to change the methodology, on the "call for comments" of Annex 2b. All reactions were positive, asking for more information. A general question was, however, how to create such data for other countries. Scientists from England, Germany, France, Sweden, Spain and Portugal, indicated that they had 'guestimates' on integral prevention costs for their own country, but not yet on the marginal prevention costs.*
[54] *The availability of recent and relevant LCA data for up-to-date industrial production methods is the major issue, rather than the accuracy of LCA data. See Chapter 3.6.2.*

architects and construction companies in the building industry which integrates the
cost-calculation and the environmental assessment.

With regard to operationalization of the model for designers of products and
processes, the eco-cost data has recently been incorporated in:
- the IDEMAT database
- the Ecoscan calculation program (the manual for the application of the EVR
  methodology in Ecoscan has been attached to this thesis).
Both systems will be made available, free of charge, for educational purposes. So stu-
dents can get used to the methodology, checking the EVR of their designs.

An EVR database on services is to be compiled from cases on services and product-
service combinations. This is to enable quick and easy 'guestimates' on eco-costs of
new innovative services and new product-service combinations. With regard to recy-
cling of building materials, a research programme is under development (resulting in a
PhD thesis). With regard to other services (e.g. the ICT industry), EVR data will be
compiled in a 'learning by doing' process. A research programme is recommended in
this field of knowledge.

C. The application of the model as a decision support tool

The application of the model as a decision support tool in companies and govern-
ments seems to be promising. The two dimensional approach (eco-costs and value)
provides a better understanding of sustainable strategies. The additional concepts of
the Three Stakeholders Model and the Double Filter Model seem to be promising as
well: these concepts should further be developed. The Three Stakeholders Model in
the building industry will be subject to a further PhD study and thesis. The issue of
the Tradable Emission Rights is currently under study by the Dutch government (min-
istry of VROM).

With regard to the Double Filter Model there are the following sub-issues:
- what is the bandwidth of the equal price band in Figure 9.4 of Chapter 9.4.2 ?
- what are the requirements to get the eco-costs accepted as a yardstick for
  sustainability?
- how should eco-costs be communicated to the consumers ?
- in which cases of high quality products can low eco-costs support the product
  image in a way the value is enhanced (= a higher price can be asked)?
- what is the best market communication strategy to detach the image of sustain-
  ability from the negative connotation it has got from environmental action groups?
Further research is recommended here.

With regard to the three stakeholders model in the building industry (recommended
subject to the aforementioned PhD study and thesis):
- what is the structure of this model in the building industry (Figure 9.5)?
- what are the prevailing interactions within the model in the building industry?
- are there trends that structures and/or interactions will change in the near future?

- what strategies can be used by the government to generate a transition towards a sustainable society in the building industry?

With regard to a system of Tradable Emission Rights there are many technical, organizational as well as legal questions to be resolved:
- has the government to be part of the trading system, or must the government only set boundary conditions?
- has an emission right to be a lump sum 'for ever' (equivalent to an investment in a technical measure) or must it have its yearly levy (equivalent to tax)?
- what is a fair point to start from (a system which copes with differences of companies which have BAT processes and companies which are lagging behind)?
- how are emissions to be measured?
- how is the trading system organized?
- how about import of similar products (competitive position of the companies involved)?
- what are the international legal consequences (EU, WTO)?

D. The diffusion of the model

The major hurdles with respect to communication of the model are indicated in Section 8. The next chapter will deal with the main issues of a further research programme on this issue.

10.2 Recommended actions for diffusion of the EVR model

The EVR model sets a sound basis for the analyses of the eco-efficiency of products, services, and product-service combinations. It can be applied in business strategy (product portfolio management and marketing) as well as in designing governmental policies, to trigger and sustain the transition towards a sustainable society. However, with regard to further application of the model, what is to be done to get the model widely accepted and applied in practice? In other words what are the recommended actions to be taken to support a further diffusion of the model in the world of designers and decision takers?

With regard to diffusion of the model, the following questions need to be resolved:

General
- What is the most effective way to create an up-to-date, comprehensive, open, userfriendly database?
- In what way can the (Dutch) government be convinced of the importance of the EVR model; what are the road blocks for introduction (what are the factual and emotional arguments to reject the model) and what can be done about them?

Companies and consumers
- How can 'EVR thinking' and 'EVR acting' be integrated in ISO 14001, EMAS and

Environmental product management (Dutch: 'productgerichte milieuzorg') of companies, and in the ISO 14062 for product development[55]

- What are the consequences of the EVR model for the internal value chain within companies (who gains profit and/or power, who are the losers)? Which barriers are to be expected, what are the stimuli? How has the required co-operation between departments (e.g. marketing, production, finance, environment) to be structured in terms of the organizational structure and the processes (procedures) in it?
- How can the EVR be applied in green marketing and in relation to eco-labeling? In what way can the EVR model provide a solution in the current discussions on eco-labeling? (Stevels, 2001)
- What are the crucial elements in a marketing strategy for diffusion (distribution) of the EVR model – and its application – in business?
- How are the consumers/citizens to be approached in relation to the EVR? How can they be made aware of the issue of sustainability with regard to the Double Filter Model?

Education
- How can the EVR model become part of the curricula of education in design and management?
- Which are the road blocks (what are the factual and emotional arguments to reject the model, especially by owners of 'competing' theories and models)? What is an effective and efficient introduction planning? What is the required process to arrive at such a planning?

In other words: "it is often easier to invent a solution than to implement it".
In general, it is recommended to start now with a process in which two activities will take place, concurrently, with a high degree of flexibility:
- the actual implementation itself
- research on the implementation,
since "the proof of the pudding is in the eating".

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[55] *The so called Product Environmental Care (PEC), see (Stevels, 2001).*

Postscript

On Venice

Venice is a typical example of how a downward spiral of poverty and environmental degradation can be turned around in an upward spiral of more wealth and less pollution. The local economic activities were shifted from activities with a high EVR (chemical industry) towards activities with a low EVR (the service industry).

The biggest local threat for Venice now is the increasing frequency of flooding. This problem is related to a global cause: the climate change. This problem, however, has a local answer as well: construction of a seawater barrier which is normally open, but which can be closed at high tides.

It is rather astonishing that local environmental action groups are opposing such a technical measure. They seem to stick to their fundamentalists dogmas, rather than do something about this major sustainability issue for the city!

On Diogenes ... ...

Contemplation is good for mental health in all times: in the past and in the future. However, with regard to sustainability, the "Diogenes solution" is not the right answer for our future world. To provide sufficient living conditions for so many people in our world, sound economic systems will be required, systems with a high eco-efficiency.

The right solutions of the past differ apparently from the right solutions for the future.

Annexes

Annex 1a:

From "Our common future", G.H. Brundtland

World Commission on Environment and Development

In the Preface of Brundtland (Brundtland, 1987), page xii:

"The downward spiral of poverty and environmental degradation is waste of opportunities and of resources. In particular it is a waste of human resources. These links between poverty, inequality, and environmental degradation formed a major theme in our analysis and recommendations. What is needed now is a new era of economic growth – growth that is forceful and at the same time socially and environmentally sustainable."

In the summary about 'Sustainable Development', page 9:

"Yet in the end, sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs. We do not pretend that the process is easy or straightforward. Painful choices have to be made. Thus, in final analyses, sustainable development has to rest on political will."

The definition of sustainable development ('sustainability'), as it is used in this thesis as well:
" Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
(page 43)[56,57].

[56] It is now widely recognised by economists that the goal of sustainable development is principally an equity issue. Sustainable development is a requirement to our, and future, generations to manage the resource base such that the average quality of life we ensure ourselves can potentially be shared by all future generations. High levels of eco-efficiency of product-service systems are required to achieve such a 'intergenerational equity'. (Henley et al., 1997). This thesis, however, does not touch on the awkward question of the equity within our own generation: the 'intragenerational equity', which is related to the sustainability issues with regard to the poor parts of our world.
[57] In 1990, Daly defined the operational principles for sustainable development:
set harvest levels of renewable resources at less than, or equal to, the population growth rate
set emissions of pollutants at less than, or equal to, the assimilative capacities
make research funding available for substitutes for non-renewable resources, so those substitutes are available on time minimize the materials and energy requirements of the economy, and identify maximum economic growth (Daly, 1990) (Henley at al., 1997).

Recommendations:
"...
1. Establish environmental goals, regulations, incentives and standards.
2. Make effective use of economic instruments (from 'externalized' towards 'internalized' costs).
3. Broaden environmental assessments.
4. Encourage action by industry (more action driven than merely regulation driven).
5. Increase capacity to deal with industrial hazards.
6. Strengthen international efforts to help developing countries.
..."

Annex 1b:

Morphology and Synectics

The EVR model, its several sub-systems and the single indicator - the eco-costs - ,
have been developed by applying two methodologies for designing innovative systems:
- Morphology, for the first steps to design "a model for discussion" on the basis of
  subsystems from literature
- Synectics, for the subsequent steps to refine the model by gathering (and incorpo-
  rating) opinions and ideas from experts of the specific fields.

A short description of these two methodologies are presented in this Annex.

Morphology, see Figure A.1.1

One of the important aspects of innovation and invention is, that one should avoid to
"invent the wheel" again, i.e. neglect the good ideas which are already available.
Morphology is one of the methodologies which suppresses the natural behaviour of
people to neglect a system invented by other people, because there is a flaw in it.
Morphology is focussed on the good aspects rather than the poor aspects of existing
systems. The basic idea of morphology is that every system (A, B or C) can be
described as a set of subsystems (1 through 6). Strong aspects of a system are caused
by sound subsystems, weak aspects by poor subsystems. Applying the matrix of
Figure A.1.1, one can select the best of each subsystem, and combine this to a new
solution (system D, in this particular case composed of A1, B2, C3, C4, B5 and A6).
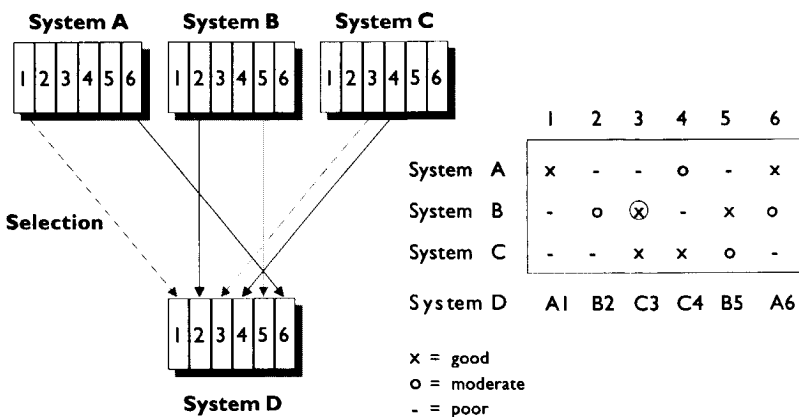
Fig. A.1.1: Morphology.

Synectics, see Figure A.1.2

Synectics is a name for one of the best methodologies to facilitate the process of innovation and invention. It has been developed after comprehensive studies by MIT (Massachussetts Institute of Technology) on the question why some R&D groups were more successful than others (in American corporations which had big successes in innovation, like 3M). In this Annex only the two major aspects of Synectics are dealt with: the 'itemized response' and the 'listening curve'.
In synectics brainstorming and morphology are combined in a continuous process (which might take days, weeks or even months). It is called 'itemized response'. The basic principle here is that, when a team member of a research group proposes an idea, this idea is not rejected by the others because there is something wrong with it, but is analyzed to determine the good elements/aspects ('items') of it. The 'items' of several previous ideas are then combined into a new proposal. This process is continued until the team is convinced that they have found the best possible solution. Such a design process is not only very constructive from the technical/systematic point of view, it is also very motivating for the team members to create something together with fast results ("positive energy").
In synectics it is emphasized that the rule " think before you speak" , is damaging for listening carefully. In meetings people often stop listening to prepare what they have to say next. They often miss the quintessence of what the previous speaker has to say, which is killing for the 'itemized response' analyses. Especially in multidisciplinary teams, project managers and facilitators of design sessions have to make sure that all participants understand a proposal before analysing it in the team (the fact that people are listening with different paradigms is a complicating factor in multidisciplinary teams).
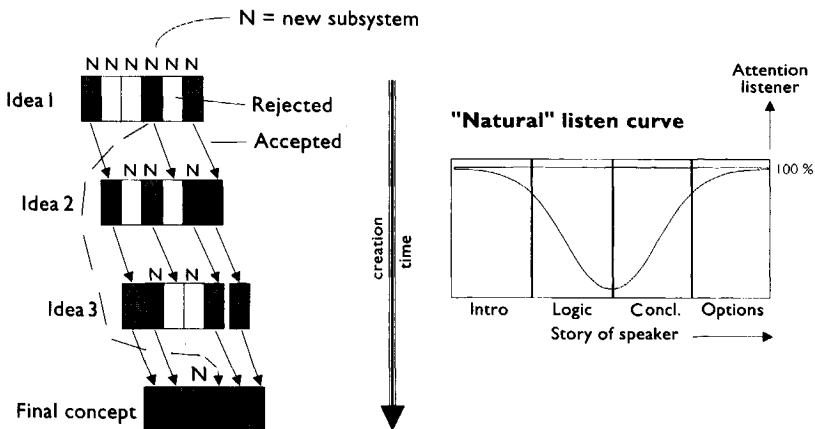
Fig. A.1.2: Synectics.

Annex 2a:

Background information on norms for sustainability.

Concentration levels.

For The Netherlands there is a set of 'target concentration levels' (Dutch: 'streefwaar-
den') for 210 pollutants, which are to be used as 'norms for sustainability', known as
the 'milieukwaliteitsnormen INS '97'[58]. This data set has been developed on scientific
grounds (as far as it was possible) to provide a solid basis for the environmental poli-
cy of the Dutch government.
The 'target concentration levels' are derived from risk assessment for each pollutant,
and are based on the following three parameters:
-   the Maximum Allowable Risk Level (Dutch: MTR)
-   the Negligible Risk Level (Dutch: VR), being 1/100 of the MTR
-   the Natural Background Level.

The MTR is a level at which 95% of the potentially resident species are safeguarded
when there are no other pollutants (for carciogenics: less than 1 fatal illness per 1
million inhabitants). The discussion about the MTR is, however, that a *combination* of
pollutants might cause a more severe situation. Therefore the VR, in most cases 1/100
of the MTR, is introduced as a level which can be considered as safe. However, in
some cases the VR is lower than the Natural Background Level.
Therefore the 'target concentration level' for a pollutant is:
-   the VR when the VR is more than the Natural Background Level
-   the Natural Background Level when this is more than the VR.

One may conclude that the set of 'target concentration levels' is the best guess which
can be made at this moment, given the state of science. Although further develop-
ments can be expected, the changes in this kind of data during recent years are not of
a drastic character. Thus this set of 'target concentration levels' may be considered as
good enough for the time being.

The situation with regard to the greenhouse effect seems to be more blurred. It is
not clear which concentration of greenhouse gasses is sustainable.
The only facts which are available, are the political decisions of Kyoto, and the 'guts
feel' of the majority of the experts, who think that a reduction of 50% in the far
future will be good enough (Gielen, 1999).

[58] *Integrale Normstelling Stoffen, milieukwaliteitsnormen bodem, water, lucht, december 1997,
Interdepementale Werkgroep Integrale Normstelling Stoffen. See also World Health Organization, 1995,
Update and revision of the Air Quality Guidelines for Europe and the Water Quality Guidelines for Europe.*

The relationship between the concentration and the damage.

It has to be mentioned here that the relationship between the concentration of a pollutant and its damage is not known for any of the pollutants: is the relation linear? logarithmic? s-curve type? See Figure A.2.1. It is obvious that one point on the curve (the MTR) is much easier to determine than the shape of the total curve.

Most of the models of a single indicator based on the *damage* of emissions, implicitly assume a linear relationship between emission and damage. This requires a linear function through the origin of the concentration-damage curve (see Figure 1) which is not likely to be the situation in reality!
This is one of the basic flaws in damage-based models (Goedkoop, 1995).
Prevention based models don't apply a concentration-damage relationship: prevention measures have to bring the concentration under the Maximum Allowable Risk Level, where damage is negligible. Prevention based models apply therefore only *one point* on the damage-concentration relationship of Figure A.2.1.
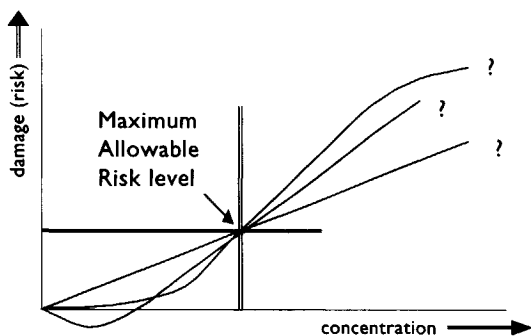
Fig. A.2.1: The shape of the concentration-damage curve for pollutants is not known

Emission rates

Starting from the situation that the set of 'target concentration levels' is fairly well known, it is, however, not easy to calculate the corresponding 'maximum sustainable emission rate'.

When the rate of decay (or absorption) is known, it is possible to determine the 'maximum sustainable emission levels' because these levels can be calculated for the "steady state of a closed region" (i.e. the total sustainable emission in that region is set equal to the decay or absorption rate of that pollutant at the maximum allowable air or water concentration). When we assume a (pseudo)first order reaction for decay or absorption, the equation for the 'maximum sustainable emission rate' can be derived:

first order reaction: $\dfrac{dc}{dt} = \dfrac{\phi}{V} - k * c,$ [A.2.1]

where: c is the concentration of the pollutant (kg/m^3)
          t is the time (s)
          k is the reaction rate constant for the decay or the absorption($1/s$)
          ϕ is the emission rate (kg/s)
          V is the volume of air or water (m^3)

for the steady state: $k * c = \dfrac{\phi}{V}$ [A.2.2]

or, for the maximum sustainable level: $\phi_{max} = k * c_{max} * V$ [A.2.3]

where: ϕ_{max} is the maximum emission rate which is just sustainable (kg/s)
          c_{max} is the maximum allowable concentration of the pollutant (kg/m^3)

In reality it is more practical to define equation [A.2.3] in terms of the "immission rate", I , which is defined as the load rate of pollutant (kg/s) per square meter of area, A:

$$I_{max} = k * c_{max} * d$$ [A.2.4]

and: $I_{max} = \dfrac{\phi_{max}}{A}$

where: d represents the average thickness of the polluted layer:
          e.g. in water: the volume of water in a certain area divided by the area surface,
          in air: for summer smog the height of the inversion layer in the air,
          in soil: the penetration depth of the pollutant.

Unfortunately, there is no full consensus about decay and/or absorption rates (e.g. part of the debate on global warming concentrates on the absorption rate of the earth of CO_2). De Boer (Dellink et al., 1997) gives a calculation for the Dutch situation for acidification, eutrophication, summer smog, winter smog and heavy metals (Zn), based on several Dutch calculation models. These calculations form the basis for verification of the norms which are given for each class of the virtual pollution prevention costs '99. Similar calculations (the 'fate analyses') have been made in the Eco-indicator '99 model (Goedkoop, 1999), applying several European models to it.

Marginal prevention costs

A totally different norm for sustainability is the 'marginal prevention costs', applied by environmental economists. The basic reasoning behind the marginal prevention costs

can be summarized as follows:
- prevention of emission of production processes will require technical measures ('end of pipe' as well as 'process integrated')
- these measures will cost money (e.g. Euro/ 'kg prevented emissions')
- on the road to a sustainable economy, we will introduce the most cost effective measures first
- the last and most expensive measure for pollution prevention, required to reach a sustainable economy, has a certain level of costs per 'kg prevented emission': the marginal prevention costs.

This is depicted in Figure A.2.2. The measures to be taken form curve a. The marginal prevention costs are determined by the slope of curve a where the norm for sustainability is met: the slope of line b.
Note that the total required prevention costs to reach the norm are less than the distance to the norm multiplied by the marginal costs (as is indicated by line c). See also Annex 2c for a further explanation. One of the advantages of the marginal prevention costs as a norm is that these costs do not change when measures are implemented, where the "distance to target" changes continuously in time.
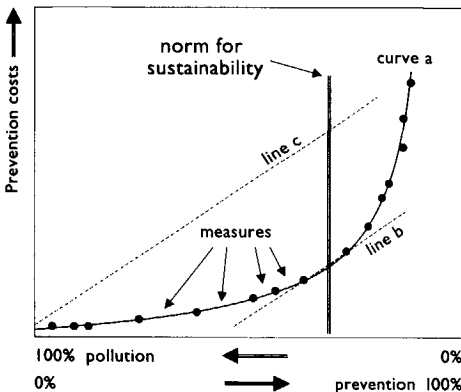
Fig. A.2.2: A typical cost curve of reduction of pollution and the marginal prevention costs.

There are several ideas to trigger the required change process on a National, European or even world wide, level. To name a few:
- taxation of emissions ("the pollutant pays") at the level of the marginal prevention costs: companies will apply the cheaper measures, where possible, rather than pay the tax
- introducing 'tradable emission rights' at the price of the marginal prevention costs: again, companies will use each opportunity to apply measures which are cheaper than these emission rights
- agree with the industry that they will introduce a list of measures (of which the most expensive measures are at the level of the marginal costs), a so called 'convenant' to apply the 'best practices'
- force the industry to introduce the measures up to the level of the marginal pre-

vention costs and ban the processes which cannot be accepted (for example the ban on CFCs)
- try to influence the demand side of the market to accept environmentally clean products only.

The prerequisite of these ideas is that our society is prepared to pay the extra costs up to the level of the marginal prevention costs in order to create a sustainable world, and that the measures have to be introduced in the most cost-effective way from the National point of view. See also Chapter 9 and Annex 2c.

Since the concept of marginal prevention costs is easy to understand, it generates a lot of questions such as:
- what is the level of sustainability for each class?
- what is the 'willingness to pay'[59] for each class?
- will 'economies of scale' and technological innovation make pollution prevention less expensive, resulting in a lower level of marginal prevention costs?
- will economic growth and growth of the population make the sustainability norms harder to reach in future, resulting in a higher level of marginal prevention costs?

The model of the virtual pollution prevention costs '99 is based on the present situation, and not on the future. The validation of the levels of marginal prevention costs are based on the present state in 'virtual' terms ("what if we already had taken the measures now"). These calculations are based on the aforementioned 'target concentration levels' (Dutch: 'streefwaarden'), which are accurate enough "to begin with". The last measure for pollution prevention in the calculation of the marginal prevention costs is to be regarded as a 'moving target': the future will bring us the real values of marginal prevention costs (hence .....'99).

The fact that the maximum level of emissions for a sustainable society is not yet fully known, is often used as the main argument to reject prevention oriented models as being too vague. It is used as an argument to choose a damage oriented model for calculations. A rather bizarre situation since the main elements for calculations on the basis of damage are not available at all:
- the shape of the concentration-damage curve (where the fact that the curve is non-linear is causing enormous complications in such damage based models)
- a realistic methodology how to compare a fatal illness with dying trees and/or distinguishing species (Finnveden, 1997).

59 *The willingness to pay (WTP) must not be confused with the marginal prevention costs. The WTP (and the willingness to accept compensation, WTAC) are based on valuation of damage. Although many attempts have been made, there are still a lot of methodological flaws in such a 'non-market valuation', and 'non-use valuation' (Henley et al., 1997). There have been two major applications of the WTP:*
- *the valuation of the damage caused by the Exxon Valdes (by the Contingent Valuation Method, CVM)*
- *the EPS method (Steen, 1996)*
One of the main conclusions is that information is crucial for those valuation systems: for many environmental issues, awareness is needed to bring the WPT above the level of the marginal prevention costs (to make the level of marginal prevention costs politically accepted).

Regionality

A fundamental problem in the calculation model is how to deal with 'regionality' (apart from calculations on the greenhouse effect, since this effect is global).
In areas with a high density of population and industrial activity, stringent and expensive measures are required (to safeguard the sustainable level of the ratio ϕ/V or I/d, see equation [A.2.3] and [A.2.4]). From the mathematical point of view, however, higher emissions are allowed when they are diluted in a higher volume (bigger area). As a consequence, the marginal prevention costs will be higher when the calculation is made for the Dutch province of Zuid Holland, than it is for The Netherlands, or for Europe. Damage based models suffer from the same fundamental problem.
From a philosophical point of view, it seems that dilution of emissions have to be avoided in the real world (so also in the calculation models). At the same time, best practices for pollution prevention should be applied on a global level to prevent 'export' of sustainability problems.

The aforementioned approach means that norms have to be calculated for areas with a high density of population and industry (e.g. The Netherlands, the western part of Germany, the areas of Los Angeles, Tokyo, etc.). The required pollution prevention measures should then be applied world wide, however, not at a cost level which is higher than the marginal prevention costs (example: a windmill is only a good solution in areas with a lot of wind). So the idea of economic feasibility ('cost effectivity') plays an important role in such a model.

Annex 2b:

Call for comments

The publication of the theory of Section 2 (Vogtländer et al., 2000), was accompanied by the following "call for comments":

1. We are very interested in similar calculations for other regions outside the Netherlands:
   a. Do you have similar calculations (referring to Figure 2.3 - 2.7) for any of these classes or for other pollution classes?
   b. For CO_2 reduction: what are the costs for CO_2 reduction measures in your region and at what level of marginal prevention costs does your region comply with "Kyoto", and at what level do you expect a 50% reduction?
   c. Do you have any examples of "industrial best practices" and benchmarking, and what are the norms in these examples (emission levels?, emission prevention levels?, emission prevention costs?).
2. Do you have any suggestion to extend the classes in this article with another class, and how do you arrive then at the marginal prevention costs for that class (e.g. hindrance of noise).
3. Especially for developing countries, it is possible to make a quick estimate of the pollution prevention costs (1. assess the regional environmental problems; 2. make a list of measures to be taken; 3. determine the marginal prevention costs for each class). This could result in a set of data for each different region. Such a calculation model, however, makes sense only when the Life Cycle Inventory of emissions does take into account the region where the emission occurs, which adds quite some complications to the current LCA methodology. Do you feel there is a need for such an enhancement of the LCA methodology? Why and for which type of situations? Or do you feel that the LCA methodology should be kept simple.
4. The underlying idea of point 3 is that the developing countries cannot afford the prevention measures of the western world, and they don't need them (because their emission levels are low). However, one may argue differently: in order to gain maximum environmental protection, best practices in the field of prevention measures should be applied world wide and "export of environmental problems for economic reasons" should be suppressed. Such an approach would require world wide standards for prevention measures and/or prevention costs (in Euro or US $ per kg equivalent per class). In such a model, regions with high emissions will have a high economic burden to prevent these emissions, regardless of their own sustainability norms and their economic situation. As a consequence the western world has to subsidize the developing countries where necessary. How should we arrive at such world wide norms? Do we expect then norms which will be totally different from the norms presented in this article, and if so why?

When you have comments on these questions and/or you have comments on any specific aspects of the calculation method which is presented in the article, please contact us by e-mail: Joost.Vogtländer@AimingBetter.nl

Annex 2c:

Why marginal prevention costs instead of total prevention costs.

A frequently asked question on the presented theory of the pollution prevention costs (and the eco-costs) is related to the choice of the marginal prevention costs (Euro/kg) to monetarize the seven classes of emissions. Why not the total costs (Euro) divided by the total emission reduction (kg)? (Referring to Figure 2.2 through 2.7).

There are 3 methodological reasons to take the marginal costs as a norm:
1. the marginal costs are more stable in time (during the transition towards a sustainable society) than the total costs, so the bases on which calculations are made do not change during such a transition.
2. the marginal costs are an estimation of future taxes or tradable emission rights, related to individual products in the event that nothing is done to prevent the related emissions; the marginal prevention cost are therefore relevant for product strategies of designers and business managers.
3. the marginal costs are related to specific prevention measures (Best Available Technologies), one for each class of emissions, which makes it plausible that the same marginal prevention costs will apply - in the long run - to all EEC member states.

These 3 reasons are explained in more detail hereafter.

Point 1.
The marginal prevention costs are more stable in time (during the transition towards a sustainable society). This is depicted in Figure A.2.3. for the logical assumption that society will take the most cost-effective measures first. It is shown in Figure A.2.3 that the total prevention costs C (Euro) divided by the total emissions which are still to be tackled, ΔE (kg) ,will change in time: in the beginning the ratio C / ΔE is rather low, at the end this ratio grow to the ratio of the marginal prevention costs (the slope of line b). However, the marginal prevention costs (Euro/kg), being the slope of line b, will remain constant throughout the total transition process.

Point 2.
The marginal prevention costs are an estimation of future taxes or tradable emission rights related to individual products in the event that nothing is done to prevent those emissions. The assumption here is that the government will try to force industry to take the required actions by either taxes or tradable emission rights at the cost of the marginal prevention costs. This is further explained in Chapter 9.
Even when the transition is enforced by other regulations (such as the Dutch 'convenants'), the marginal prevention costs are a good yardstick for business strategies: measures below the prevention costs have to be taken, measures above the yardstick should be avoided since they are not cost-effective.
See Annex 9a for more details on how, and in what extent, 'external' costs become 'internal' costs of a product.
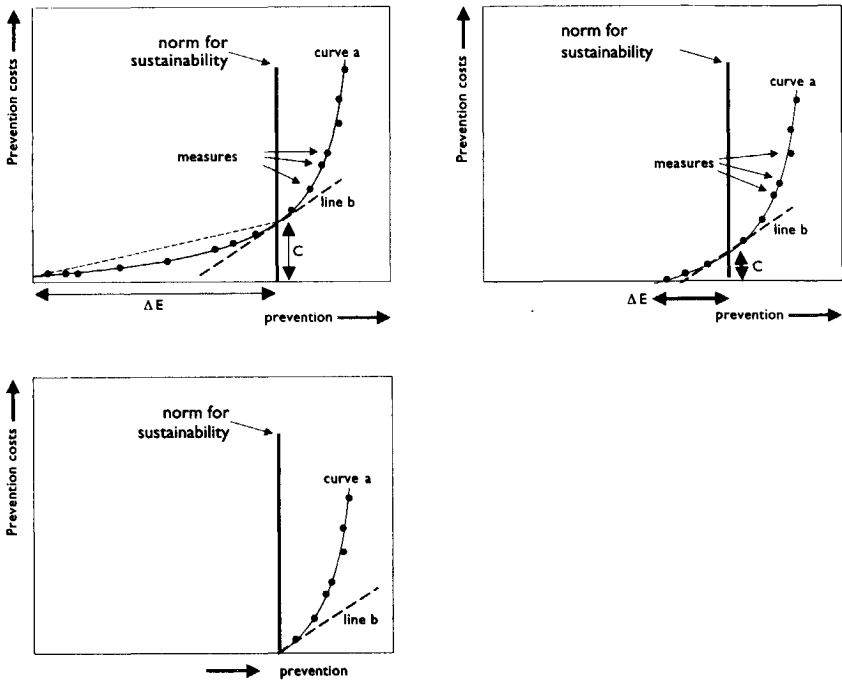
Fig. A.2.3: The transition towards a sustainable society (top left: current situation, top right: during the transition period, lower left: final sustainable situation).

Point 3.

The marginal prevention costs are related to a specific prevention measures (Best Available Technologies), one for each class of emissions. This makes it plausible that, in the long run, it can be expected that the same marginal prevention costs (i.e. the same Best Available Technologies) will apply in all EC countries. This is in line with the current policy within the EC with regard to environmental protection (the IPPC Directive): it enforces the member states to take the same measures in order to keep the industrial competitive playing field levelled.

It has to be mentioned here that the measures which are relatively cost-efficient (the measures at the left hand side of curve a in Figure A.2.3) are in most cases related to industrial activities, since concentrations of emissions in industry are relatively high and therefore easy to tackle (compared with the more diffuse emissions from domestic use). The right hand side of the curve, in combination with the norm for sustainability, is predominantly determined by domestic emissions, and therefore a function of the density of population in a certain region. It is expected therefore that norms within the EC will be governed by norms for densely populated areas (such as the triangle London-Paris-Dortmund).

Annex 3:

Call for comments

The publication of the theory of Section 3 (Vogtländer et al., 2001a), was accompanied by the following "call for comments":

1. In the EVR model, economic allocation is applied in two cases:
   a. When subsystems are shared between many product types and the physical relationship is not determined by one parameter, like mass, volume or time. The EVR model applies then equation [3.7]
   b. When there is a linear relationship between value and a physical parameter like mass, volume or time. In these cases, there is no difference between the "physical proportion" and the "economic proportion".

We feel that the use of economic allocation should be defined better than "only where physical relationship cannot be established". We suggest a list of criteria which have to be fulfilled to allow economic allocation, like:
- relative stable prices in a transparent, free, and open market
- a linear relationship between value (price) and mass, volume or time.

Are there any suggestions to complete this list? Are there any comments?

2. In the EVR model the 'bonus' of open loop recycling is allocated to the 'new product', and consequently not to the 'old product' (otherwise recycling is counted twice). Our choice was grounded on methodological aspects (avoiding endless loop systems and avoiding the methodological consequences of the build-up of materials in the cycle for products with a long life time). We are aware of the fact that our approach is not in line with the current practice of allocating the benefits of recycling to the 'old product'. Are there any comments on our choice, and/or are there any suggestions for an alternative (hybrid?) solution for allocation?

Annex 4:

Economic Allocation in LCA, ISO 14041

The norm ISO 14041 describes a three step procedure for allocation in chapter 4.4.2:

Step 1:   *Whenever possible, allocation should be avoided by:*
      1. Dividing the unit process to be allocated into two or more subprocesses and collecting the input and output data related to these subprocesses;
      2. Expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 5.3.2. (Function, functional unit and reference flow).

Step 2:   *Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way which reflects the underlying physical relationships between them; i.e. they shall reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system. The resulting allocation will not necessarily be in proportion to any simple measurement such as the mass or molar flows of co-products.*

Step 3:   *Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way which reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.*

Under the point 'allocation procedures for recycling', chapter 4.4.3:

An open loop allocation procedure applies to open loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties. The allocation procedures for the shared unit processes mentioned above should use:
- *physical properties*
- *economic value (e.g. scrap value in relation to primary value), or,*
- *the number of subsequent uses of the recycled material (e.g. rubber used in a tyre to rubber in the shoe sole to energy recovery from rubber incineration).*
as the basis for allocation.

Annex 5a:

The costs-price-value model

In elaborating the concept of eco-efficiency as defined by the WBCSD and the basic idea of the EVR model as depicted in Figures A.5.1 and A.5.2, it is essential to understand the differences between costs, price and value as they are defined in modern management theories (like Total Quality Management and/or Continuous Improvement).

The classical management paradigm to describe the function of costs, price and value is depicted in Figure A.5.1. In the eyes of the producer, profit is a result of the difference between the costs of a product and its price. Managers try to reduce the costs as much as possible and get a price as high as possible. However, managers know that the end user (consumer) will buy the product only when, in the eyes of these consumers, the perceived value is higher that the price.
In the classical management paradigm, the manager has no choice: when the price gets too high, there will be no buyers, so the only thing he can focus on is reducing costs. In this paradigm, measures for environmental protection add costs, so have to be kept to a minimum.

A product in the eyes of the manufacturer   A product in the eyes of the consumer
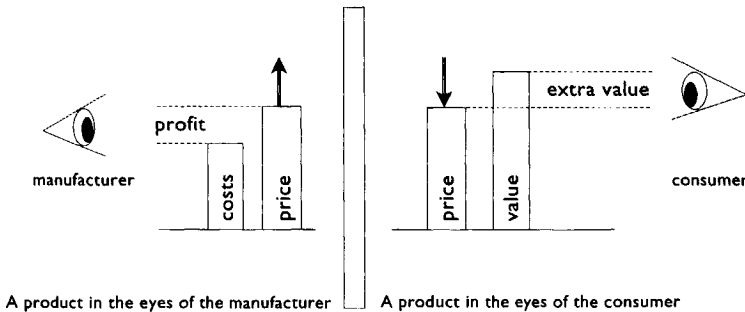
Fig. A.5.1: The classical paradigm is "price driven", which leads to "cost cutting".
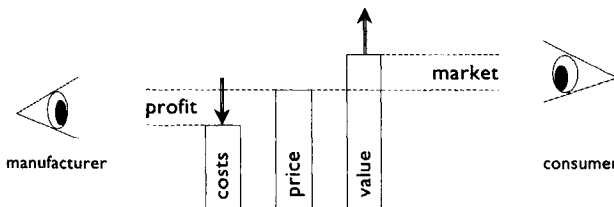
Fig. A.5.2: The new management paradigm is about enhancing the value/costs ratio".

In the modern management approach, the strategic focus is on the *ratio* of value and costs, as is depicted in Figure A.5.2. A big difference between value and costs create a variety of strategic options for setting the right price (more profit by optimization of margin per product versus sales volume).

In the classical management paradigm, higher value ("quality") leads always to higher costs. In the modern management paradigm that is not the case: there are many management techniques that lead to a better value/costs ratio. Examples are: logistics (better delivery at lower stock levels), complaint management (satisfied customers with less claims), waste and quality management (less materials better quality). All these examples - there are many more in the field of Total Quality Management and Continuous Improvement - lead to more value at less costs. This is called "the double objective" for managers (Vollmann, 1996) and opens new perspectives to support eco-efficiency (it supports the first part of the eco-efficiency definition of the WBCSD). See also (Porter et al., 1995).
Note that this modern management philosophy is much more than just "adding services" to existing products. It is about carefully improving the quality of products and services (as perceived by the customer!) by eliminating the "non value added" energy, materials and work.

The question is now whether these modern management techniques always lead to better eco-efficiency. The answer is no (e.g. the use of pesticides in agriculture results in a better value/costs ratio but not in a better level of environmental protection). That is why the aforementioned definition of eco-efficiency of the WBCSD adds: "....while progressively reducing ecological impacts .....".
For this reason, the "virtual eco-costs" as a single indicator for sustainability has been introduced in the EVR model of Figure 3.2. In this way the "cost structure" of a product (including services) is linked to the related ecological impacts and material depletion.

Annex 5b:

The Customer Value model of Gale

General

In his book 'Managing Customer value', Bradley T. Gale has proposed a model to quantify the value of a product-service system in order to be able to analyse the competitiveness of a product portfolio of a company. This book has been written in 1994 after the PIMS study ("Profit Impact of Marketing Strategy"), a statistic analysis on 3500 American companies, (Buzzel et al., 1987). This study had revealed that the main drivers for company profits were "relative quality" and "relative market share", see Figure A.5.3.
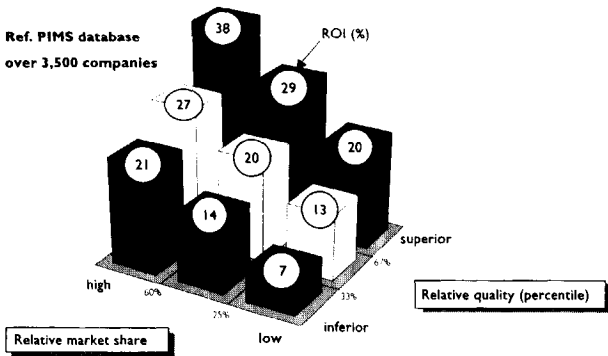
Fig. A.5.3: Quality and market share both drive the profitability of companies
         Note that ROI is 'Return On Investment' which is the ratio of profit and invested capital.

The route to a high profit is clear: via a high 'relative quality', a high 'relative market share' can be achieved, resulting in a high ROI. But the question then is how to achieve a high relative quality, being a high quality at the right price. The key to this question is to focus on the quality dimensions (Garvin, Chapter 5.2) that are important to the customers (as perceived by the customers). There are two options:
1. either improve the quality/price ratio of the quality dimensions which are important to the customers
2. or try to influence the customer preferences in the direction of those quality dimensions of your own products which are relatively high in comparison with the competitors.

Option 1 is obvious: companies have to deliver products with a good quality/price ratio. Option 2 is often combined with option 1. When a car manufacturer has developed a relatively safe car, this manufacturer has to make the market aware of this fact and has to make it an important quality dimension at the moment of purchase. The same applies to the issue of the environment. Only the right marketing strategy will

result in the desired situation that the product is perceived as better at the moment of purchase.

The model is explained here by an example, providing the main methodology, its characteristics, and the philosophy behind this model[60]. The (slightly simplified) methodology comprises three steps:

Step 1.   Assessment of the 'perceived quality ratio' of the product-service system
Step 2.   Assessment of the 'perceived price ratio' and the 'fair price'
Step 3.   Assessment of the strategic consequences.

Step 1. Assessment of the 'perceived quality ratio'

Since most of the strategic marketing analyses are confidential, we will use here a hypothetical example of vegetables, where a 'bio-vegetable' (no use of pesticides) is compared with the normal vegetable. The comparison is made by a panel of consumers, as they perceive the relative ratings (1 is the lowest score in rating, 9 is the highest score in rating). The results and the calculation scheme are given in Figure A.5.4.

(1) Aspect	(2) Importance	(3) Q rating Bio-product	(4) Q rating Normal product	(5) ΔQ rating = (3) − (4)	(6) 'weighed' = (5) × (2)
Taste	0.2	8	6	+2	+0.4
Appearance	0.2	6	8	-2	-0.4
Health aspects	0.2	8	5	+3	+0.6
Presentation	0.1	7	8	-1	-0.1
Availability	0.2	6	8	-2	-0.4
Environment	0.1	8	5	+3	+0.3
Total	1.0	7.1[*]	6.7[*]		+0.4

[*] This is the weighed average quality = sum of quality rating × importance

Fig. A.5.4: Calculation scheme of the weighted quality rating of a product.

The 'perceived quality ratio' is now defined as:
   7.1 / 6.7 = 1.06
so the bio-product is rated 6 % better in terms of perceived quality.

Note that this rating depends on the characteristics of the people on the panel. The Q rating as such in columns (3) and (4) don't vary much with the people on the panel. The importance of column (2), however, is very sensitive for the type of people on the panel (and therefore the so called 'market niche'). A different marketing strategy is needed for a different market niche.

Step 2. Assessment of the 'perceived price ratio' and the fair price

In this case the perceived price ratio is simple: it is the ratio of prices for both product types. In other words, when the bio-product is 15% more expensive, the per-

---

[60] The model has been linearized and slightly simplified to bring it in line with the wide spread methodology of the 'Decision Matrix'.

ceived price ratio is 1.15[61].

The market position of the bio-product (in relation to the normal product) is depict-
ed in Figure A.5.5. The dotted line in Figure A.5.5 is the 'fair price' line. It represents
the value (in terms of money) of quality. Everything below the fair price line is per-
ceived as too expensive; everything above the fair price line is perceived as attractive
in terms of 'value for money'. In this case, the panel stated that a maximum extra
price of 10% for the bio-product was acceptable. In other words: for the majority of
the people on the panel a 'perceived price ratio' of 1.1 was just acceptable (as a maxi-
mum) at the 'perceived quality ratio' of 1.06. The fair price line is then a straight line
through (x=1;y=1) and (x=1.1;y=1.06). The actual perceived price ratio (1.15) of the
bio-product is then too high in comparison with the value of the product.

The first reaction of most people is that the price has to be lowered (in Figure A.5.5,
the market position of the bio-product has to shift to the left). Figure A.5.5 shows,
however, that there is an alternative: increase the perceived quality ratio, either by
increasing the quality or by influencing the perception (change the consumer prefer-
ences). We will analyse these options for a market strategy in Step 3.
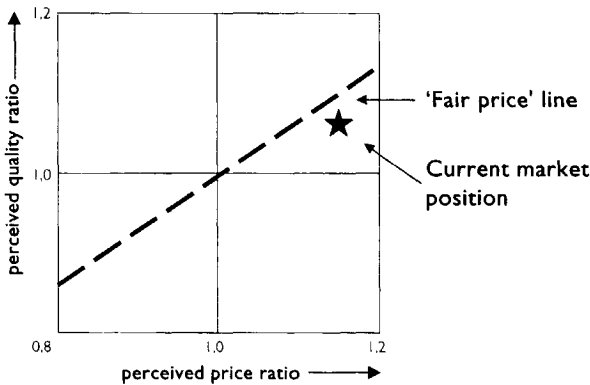
Fig. A.5.5: The 'fair price' line and the market position of a product.

Step 3. Assessment of the strategic consequences

In the above example, there are three options to bring the product above the fair
price line:
1. lower the price by at least 5% by lowering the costs of production and distribution
2. increase the quality of the product
3. change the perception of 'what is important'.

---

[61] The reason that it is called 'perceived price ratio' is that for many modern products the price is not so
clear anymore (examples: mortgages, pension funds, lease contracts, service guarantees, etc.).

The first option seems simple, but is often hard to realize in practice. When the sales volume is higher, distribution costs can be lower, but when a lower price doesn't generate the required extra volume, this option doesn't work. In general one should take care that savings in production and distribution may not harm the product quality (otherwise one is acting "pound foolish – penny wise"). Savings are only allowed in aspects which are not important to the customers. However, in this case there are no such opportunities.

The second option is more promising, especially when it is focussed on quality aspects which combine:
- a low score for the 'Q rating' ,column (3) of Figure A.5.4
- a high score for 'Importance' ,column (2) of Figure A.5.4
In this example this is the case for 'Availability' and 'Appearance'.

The third option seems to be the most attractive from the point of view of strategic marketing. The strategy here is to focus on the quality aspects with the highest scores: 'Taste', 'Health' and 'Environment'. The aim is to increase the 'Importance', column (2), as perceived by the customers. In other words, when the 'Importance' of 'Health' can be increased from 0.2 to 0.3 and the 'Importance' of 'Availability' can be decreased from 0.2 to 0.1 (the health issue becomes so important that people are prepared to get the bio-product in a specialized shop), the scores in Figure A.5.4 will change as follows:
Q rating Bio-product: 7.3
Q rating Normal product: 6.4

The result is that the new 'perceived quality ratio' is 7.3 / 6.4 = 1.14
Which is well above the fair price line.
The strategy of the three options is summarized in Figure A.5.6.
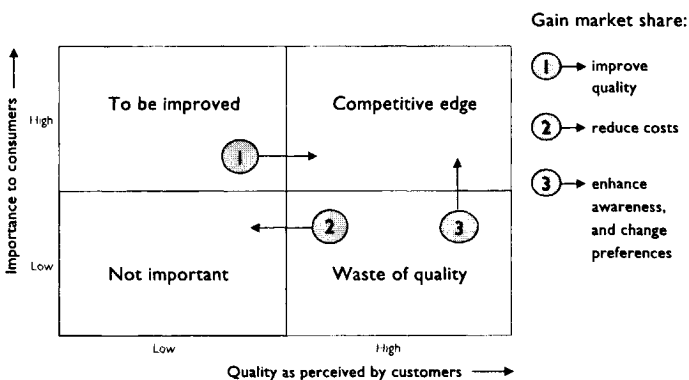
Fig. A.5.6: The market strategy of products has three options in the portfolio of Q aspects

Annex 5c:

A method to determine the value of the 3 main aspects of Quality

(the value of product quality, the value of service quality and the value of image)

Essential for the quality dimensions of Garvin (Chapter 5.2) is that they can only be judged by the customers ("as perceived by the customers", measured by customer panels or customer surveys). These quality dimensions can be expressed in terms of the 'fair price' for it, as described in Annex 5b.

The technique is that the customer is asked to estimate the value of the total product-service system in terms of the (total) fair price for it. The fair price is the highest price at which a customer is prepared to buy a product and/or service. When the price of a product is higher than the fair price, the product is considered by the customer as too expensive. When the price is lower than the fair price, the customer considers a purchase as attractive. So the fair price equals the value as depicted in Figure A.5.1 and A.5.2 of Annex 5a..

In addition to the assessment of the fair price, each quality dimension can be rated:
- in terms of the quality (=value) of each dimension (ranging from 'very poor' to 'excellent')
- in terms of importance of each dimension (ranging from 'of no value' to 'very important').

The fair price for the 'product quality', the 'service quality' and the 'image' can be determined then by calculating the weighed averages of the ratings of the Q-dimensions, and assigning the corresponding portions of the total fair price to the quality aspects. An example for an easy, linear, situation is given in the Table below. The customer is asked to assess the total fair price (= total value), the Importance Score and the Value Rating. The fair price for the value aspects is calculated then according to the scheme in the Figure A.5.7.

	Value aspect	Importance Score (1)	Value Rating (2)	(3) = (1) × (2)	(4) = (3) / 'total (3)'	'fair price' = (4) × 'total value'
a	Product Q	4	3	12	0.40	360 Euro
b	Service Q	2	3	6	0.20	180 Euro
c	Image	3	4	12	0.40	360 Euro
d	Total			34	1.00	**900 Euro**

Fig. A.5.7: Calculation scheme for assessment of the fair price for value aspects (example).

The rating system which has been applied in this example is:
- 1 = 'very poor' to 5 = 'excellent' for the value rating (column 2)
- 1 = 'of no value' to 5 = 'very important' for the score of importance (column 1)

Annex 6:

Eco-cost and costs of transport packaging

The weight of solid board trays, 0.3 (m) x 0.4 (m), 0.2 (m) high, is approximately 735 grams. The contents of such a tray is approx. 22.4 litres. The eco-costs of waste paper based board is 0.09 Euro/kg (Vogtländer et al. 2001a)[62], so the eco-costs of the solid board box is 0.066 Euro. The price of a box is about 0.45 Euro.
Per pallet there are 110 boxes (10 per layer, 11 layers high). The total pallet height is then 2.35 m (including the pallet).
The content ('net transport volume') per pallet is 2467 litres.
The total costs of transport packaging (110 solid board boxes) per pallet is 49.50 Euro.
The total eco-costs of transport packaging (110 solid board boxes) per pallet is 7.26 Euro.

The weight of plastic re-usable crates, 0.6 (m) x 0.4 (m), 0.212 (m) high, is approx. 1.75 kg. The material is High Density PolyEthylene (HDPE). The thickness of the wall construction is 1.0 cm. The bottom of 1.2 cm can be "nested" when the crate is placed on top of another crate, so the net nested height is 20 cm. The contents of such a crate is 41.3 litres. Clean crates are rented at a roundtrip price of 0.2 Euro (including the cleaning after each trip). The cost of a crate is approx. 3.85 Euro. The number of roundtrips is estimated at 30.

The eco-costs of the materials of a crate can be calculated from the pollution prevention costs of HDPE + the eco-costs for depletion: $(1.26 + 0.6) \times 1.75 = 3.25$ Euro (Vogtländer et al., 2001a). Moulding of crates is estimated at 0.14 Euro per crate.
The crates are washed with warm water (60 degrees Celcius). One litre of fresh water is needed to wash one crate. The related eco-costs are very low in comparison with the eco-costs of the crate itself: 0.003 Euro/crate.
So the eco-costs of a crate is 0.11 Euro per roundtrip.

Per pallet (1.00 x 1.25 m) there are 55 crates (5 per layer, 11 layers high). The total pallet height is then 2.362 m.
The content ('net transport volume') per pallet is 2279 litres.
The total costs of transport packaging (55 plastic crates, rented) per pallet is 11.00 Euro.
The total eco-costs of transport packaging (55 plastic crates, rented) per pallet is 6.05 Euro.

Data are summarized in Table 6.22.

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[62] *For board, the average data for modern manufacturing plants (such as the manufacturing plants in The Netherlands) have been applied, since the BUWAL data are for this case not realistic anymore.*

Annex 7a:

The 'second order' effect in calculations on species richness

In example 1 of Chapter 7.2.2, the total area of land was converted, and there was no interaction with adjacent areas. When, however, an area is *expanded* by converting a part of an adjacent area, the total effect on the SRI is more complex. In such a case, the increase or decrease of SRI stems from three factors:
1. conversion of land of the adjacent area
2. increase of S in the total area which is expanded ('second order effect' because of the increase of area in equation [7.3a])
3. decrease of S in the total remaining adjacent area ('second order effect' because of the decrease of area in equation [7.3a]).

This second order effect on S, ΔS, can be described as a function of ΔA_{TA} by differentiating equation [7.3a], see Figure A.7.1:

[A.7.1] $\quad \dfrac{\Delta S}{\Delta A_{TA}} = b * S_{1\,ha}(A_{TA})^{b-1} \quad or: \Delta S = \Delta A_{TA} * b * S_{1\,ha} (A_{TA})^{b-1}$
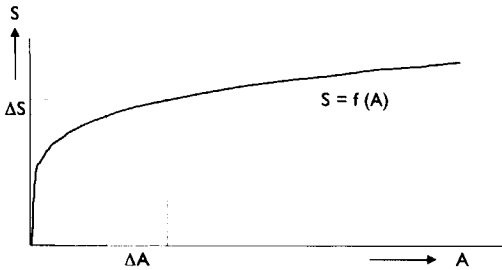
Fig. A.7.1: S as a function of A_{TA}.

The second order effect on SRI, $\Delta SRI_{secondary}$, can be found by combining [7.2] and [A.7.1] for a relatively small incremental increase, ΔA_{TA} (note: SRI is expressed here in equivalent hectare instead of equiv. m^2, and $S_{ref.}$ is assumed to be constant over this small increment):

[A.7.2] $\quad \Delta SRI_{secondary} = A_{TA} * \dfrac{\Delta S}{S_{ref.}} = \dfrac{\Delta A_{TA} * b * S_{1\,ha} (A_{TA})^{b}}{S_{ref.}}$

or

[A.7.3] $\quad \Delta SRI_{secondary} = \Delta A_{TA} * b * \dfrac{S}{S_{ref.}}$

It is obvious that equation [A.7.3] is valid for increase as well as decrease of an area, so point 2 as well as point 3 can be calculated with it. Addition of the second order effect of point 2 and point 3 results in:

[A.7.4] $\Delta SRI_{secondary} = \dfrac{\Delta A_{TA} * b_I * S_I}{S_{ref.}} - \dfrac{\Delta A_{TA} * b_2 * S_2}{S_{ref.}}$

where S_I and b_I are the S and the b of the expanded area, and S_2 and b_2 are the S and the b of the adjacent land of which a small part is converted (Note: S_I and S_2 have to be calculated with equation [7.3]).

The first order effect (the change of SRI of the converted land) can be described as:

[A.7.5] $\Delta SRI_{primary} = \dfrac{\Delta A_{TA} * S_I}{S_{ref.}} - \dfrac{\Delta A * S_2}{S_{ref.}}$

Equation [A.7.4] and [A.7.5] can be combined in:

[A.7.6] $\Delta SRI_{total} = \dfrac{\Delta A_{TA} * (1+b_I) * S_I}{S_{ref.}} - \dfrac{\Delta A_{TA} * (1+b_2) * S_2}{S_{ref.}}$

A similar calculation can be made when a piece of land is partitioned in two e.g. by a motorway. It can be calculated by applying equation [7.1] and [7.3] to the situation before and after the split:

[A.7.7] $\Delta SRI_{partitioning}$

$$= \frac{A_{TA} * S_{I\ ha}(A_{TA})^b}{S_{ref.}} - \frac{A_{TA} * \beta * S_{I\ ha}(A_{TA} * \beta)^b}{S_{ref.}} - \frac{A_{TA} * (1-\beta) * S_{I\ ha}(A_{TA} * (1-\beta))^b}{S_{ref.}}$$

$$= \left\{ \frac{A_{TA} * S_{I\ ha}(A_{TA})^b}{S_{ref.}} \right\} * \{ 1 - \beta^{1+b} - (1-\beta)^{1+b} \}$$

$$= SRI_{original} * \{ 1 - \beta^{1+b} - (1-\beta)^{1+b} \}$$

where A_{TA} is the original area, divided in a part b and a part $(1-\beta)$, and where SRI original is the species richness quality in the original (undivided) state. $S_{ref.}$ is assumed to be constant in this calculation. The result of equation [A.7.7] in terms of $\Delta SRI_{partitioning} / SRI_{original} = f(\beta)$ is given in Table 7.2.

Example:

When a new motorway will cross an 'intensive meadow' of 100 ha and split this area in two parts of 40% and 60% of the original size, the result of equation [A.7.7] is:

$$\Delta SRI_{partitioning} = 100 * (\frac{104}{250}) * 0.24 = 9.984 \text{ equiv. ha. or } 99,840 \text{ equiv. m}^2 \text{ of nature}$$

Annex 7b:

Summary of the methodology of Botanical Valuation of km² of Witte

Witte (Witte, 1998) took 'rarity' as a measure of importance for what is called 'Botanical Valuation of kilometer squares'. The methodology has been operationalized by means of the Dutch FLORBASE database. This database contains distribution data of vascular plants that grow in the wild in a national grid of 35,000 areas of one km².

The system can be summarized as follows - see (Witte, 1998) for all details -:
- 'Ecosystem types' have been defined, based on the following 4 abiotic parameters:
    - salinity (classes: fresh, brackish, saline)
    - moisture regime (classes: water, wet, moist, dry)
    - nutrient availability (classes: low, moderate, moderate to high, high)
    - acidity (classes: acid, neutral, alkaline).
    Combination of these classes resulted in 28 ecosystem types relevant for the total Dutch area.
- Groups of 'indicator species' have been defined for each ecosystem type (indicator species are vascular plants which occur only in one, two, or maximum 3 ecosystems). The 'indicator value', v, has been determined to describe the ecosystem – species relationship ($v = 1$ if a vascular plant occurs only in one ecosystem, $v = \frac{1}{2}$ if a plant occurs in one other ecosystem as well, $v = \frac{1}{3}$ if a plant occurs in 3 ecosystems, $v = 0$ if a plant occurs in more than 3 ecosystems).
- The indicator values v have been added up for all m species (vascular plants) in a km² belonging to a certain ecosystem, resulting in the 'indicator value score', N:
    $N = \sum v_m$
    So N is a weighed number of indicator species in one km².
- The maximum N in the database was determined for each of the 28 ecosystems, being the value which is not surpassed in 99.8% (!) of the cases (to rule out extremities):
    $N_{0.2}$ (being the maximum practical weighed count in one km²).
- The 'completeness fraction', C, has been calculated for each km² in the database via a quite complex procedure. This calculation, however, can be approximated within 10% by[63]:
    $C = 1$ for $N / N_{0.2} > 0.72$ (the km² is 'complete' when N is more than 72% of $N_{0.2}$)
    $C = 0$ for $N / N_{0.2} < 0.43$ (this threshold determines "…whether an ecosystem may be said to be really present in a km², instead of classifying its occurrence as 'noise' …")
    $C = (N – 0.43 N_{0.2}) / (0.29 N_{0.2})$ for $0.43 < N / N_{0.2} < 0.72$
    The linear range of C might look rather small, but when the results of the scores of C are drawn on maps of The Netherlands, the results appear to be surprisingly good in terms of relevant botanical information.

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[63] Witte applied a slightly different curve fit: $0.49 + 0.72 N_{0.2}$ for the upper threshold value and $-0.03 + 0.49 N_{0.2}$ for the lower threshold.

- Species in an abundant ecosystem type are less rare than species in a rare eco-system type. Therefore, the second main parameter in the model, V, copes with the rarity of an 'ecosystem type'.

  V is a function of the occurrence of the ecosystem type in terms of the total weighed area AW (km^2) of that ecosystem type: $AW = \sum (C \times \Delta A)$ where ΔA is 1 km^2 and the summation is for the total area of The Netherlands. AW can be regarded as the equivalent complete km^2 of a ecosystem type within The Netherlands.

  $V = (AW_{max} / AW)\ 0.63$ where AW_{max} is the occurrence $\sum (C \times \Delta A)$ of the most abundant eco-system.

  Note: V has slightly been corrected for international rare eco-systems. V ranges in the database from 1 to 9.8.
- The importance of land, Q ('Botanical Value' of 1 km^2), is calculated as:

  $Q = \sum (V \times C)$

  Note: the summation is used to cope with the situation that there can be more than one ecosystem type within one km^2.

Witte tested several valuation formulas by showing maps of the province of Utrecht (NL) to experts in the field of botany. He asked them, single blind (it was not explained to the experts how these maps had been calculated), which map they preferred. Maps based on the plants richness S did not score well. The maps based on $\sum (V \times C)$, so Q scored the best.

Witte didn't develop a national quality norm for Q. Since a norm is required to develop a single indicator, a Pareto analysis has been applied on AW (the equivalent complete km^2) per ecosystem in the database (Witte, 1998: Table 5.3). See Figure A.7.2.
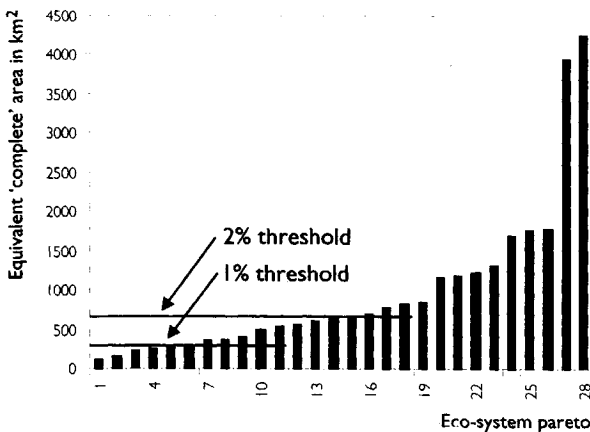
Fig. A.7.2: The equivalent 'complete' areas for the 28 ecosystems in The Netherlands, data from (Witte, 1998).

The lower line in Figure A.7.2 is the 1 % threshold level:

- The total equivalent 'complete' area, AW, of one ecosystem under this threshold is less than 1% of the total Dutch real area of 35,000 km^2.
- There are 6 ecosystems under this threshold.
- The total equivalent 'complete' area AW of the 6 ecosystems together under the threshold is 1,310 km^2, being about 3.5 % of the total Dutch real area.
- The value of V of each of the ecosystems under this threshold is more than 5.
- The corresponding norm of Q 1% threshold = 5 (this norm has been calculated for C=1 and one ecosystem in one km^2).

The upper line in Figure A.7.2 is the 2 % threshold level:

- The total equivalent 'complete' area AW of one ecosystem under this threshold is less than 2 % of the total Dutch real area of 35,000 km^2.
- There are 15 ecosystems under this threshold.
- The total equivalent 'complete' area of the 15 ecosystems together under the threshold is 5,900 km^2, being about 17 % of the total Dutch real area.
- The value of V of each of the ecosystems under this threshold is more than 3.3
- The corresponding norm of Q 2% threshold = 3.3
  (this norm has been calculated for C=1 and one ecosystem in one km^2).

The level of Q threshold = 3.3 is regarded as a realistic threshold, see the map of Annex 7e. 80% of the Dutch area on this map is below this threshold.

Annex 7c:

Measures and costs to prevent conversion of land from 'green' to 'built-up'

In this annex some general cost data are given for measures to prevent conversion from 'green' areas into 'built-up' areas. Since the cost levels highly depend on local soil conditions, the cost ranges are indicative only. The costs figures comprise the investment for construction only (excluded are the price of land, and the net present value of costs for maintenance and operation).

1. Enhance the density of industrial areas (less open space, medium or high rise warehouses)
Range of prevention costs: 0 - 100 Euro per m^2

System 1a. Less open space between buildings (normally reserved for future expansion, which in most of the cases never materialize), no extra costs

System 1b. Medium and high rise warehouses instead of low warehouses, extra costs max. ca. 100 Euro per m^2

2. Enhance the density of population of built-up areas (try to accommodate more housing in cities)
Range of prevention costs: 350 - 550 Euro per m^2
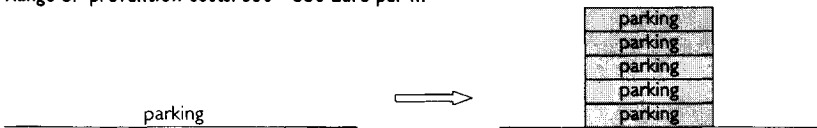
System 2a. Multi store parking houses, extra costs 350 - 550 Euro
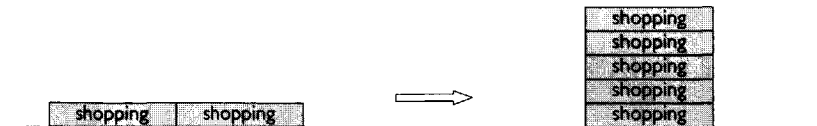
System 2b. Multi store shopping centres, extra costs 350 - 550 Euro (structural only)

3. Cover parking places, roads and railway lines Range of prevention costs: 350 - 550 Euro per m^2
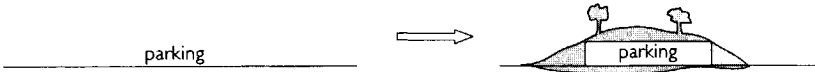
parking ⟹ parking

System 3a. A park on top of parking, extra costs 350 - 550 Euro

road ⟹ road — — — ditch

System 3b. A cover for roads and railway lines, extra costs 350 - 550 Euro

4. Build underground Range of prevention costs: 700 – 2200 Euro per m^2

parking
parking
parking
parking
parking

rail

rail
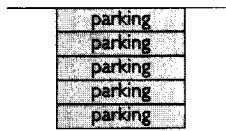
System 4a.
Underground parking,
700 - 1500 (Euro/m^2)

System 4b.
Cut and cover,
1000 - 1500 (Euro/m^2)
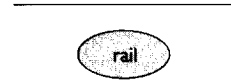
System 4c.
Tunneling,
1500 - 2000 (Euro/m^2)

Annex 7d:

The eco-costs of land conversion in relation to the H2O cycle in Dutch polders

One of the sustainability issues in the Dutch polders is related to the rain water storage volume (Dutch:'waterberging') in the polder as well as in the 'boezem' (= water storage volume directly around the polder). The root causes of the emerging problems are:
- the conversions from green areas to built-up areas (because of increasing population and welfare, and expansions of industry and horticulture)
- the increase of peaks in heavy rainfall in the autumn (because of the greenhouse effect?).

Key to the problem is that falling rainwater that peaks over 2 – 4 days, cannot be absorbed anymore by the land: the water immediately flows off into the sewage systems and cannot be pumped away fast enough. The only solution to this problem is to restore the local holding capacity of rainwater (although enhancement of pumping capacity is required as well).

The characterization system with regard to the rainwater hold-up is based on the sum of:
- the interception of rainwater by plants and trees
- the surface storage of water (in puddles)
- the infiltration storage in the soil.

The interception of rainwater by plants and trees, I_t (in mm rainfall), can be characterized by the formula of Horton (Horton, 1919),(Kibler, 1982):

[A.7.8] $\qquad I_t = (a + b * P^c) \left(\dfrac{A_{occupied}}{A} \right)$ (mm rainfall),

where a, b, and c have been provided for several types of vegetation in the table of Figure A.7.3. P is the maximum expected rainwater peak. $A_{occupied} /A$ is the ratio which is occupied with vegetation of a certain area.

The storage of water at the surface of the land in puddles, I_s , can be characterized by:

[A.7.9] $\qquad I_s = \left(\dfrac{V}{A} \right) * 1000$ (mm rainfall),

where V is the total volume of water (m³) in the puddles at the surface A

Type of vegetation	a	b	c
Orchards	1.0	0.18	1
Chestnut, hedge and open	1.0	0.20	1
Chestnut, in woods	1.5	0.15	1
Ash, hedges and open	0.4	0.23	1
Ash, in woods	0.5	0.18	1
Beech, hedges and open	0.75	0.23	1
Beech, woods	1.0	0.18	1
Oak, hedges and open	0.75	0.22	1
Oak, woods	1.25	0.18	1
Maple, hedges and open	0.75	0.23	1
Maple, woods	1.0	0.18	1
Willow shrubs	0.5	0.40	1
Elm, hedges and open	0.75	0.23 × 5	0.5
Elm, woods	1.0	0.18 × 5	0.5
Basswood, hedges and open	0.75	0.13 × 5	0.5
Basswoods woods	1.25	0.10 × 5	0.5
Helmlock and pine, hedges and open	0.75	0.20 × 5	0.5
Helmlock and pine, woods	1.25	0.20 × 5	0.5

Fig. A.7.3: Values to be used in equation [A.7.8].

The infiltration storage in the soil, I_f (in mm rainfall), can be characterized by:

[A.7.10] $I_f = d * p * 1000$ (mm rainfall),

where d is the allowable temporary rise of ground water level (in meters) and p is the effective porosity of the soil

The water storage quality indicator of land, IQ, is defined as:

[A.7.11] $IQ = I_t + I_s + I_f = (a + b * P^c) + (\dfrac{V}{A}) * 1000 + (d * p * 1000)$,

For land covered with asphalt or concrete $I_f = 0$ and $I_s =$ approx. 2.

The norm for infiltration quality, IQ_{norm}, is determined by a course gravel infiltration bed, $p = 0.33$:

[A.7.12] $IQ_{norm} = d * 0.33 * 1000$

The category indicator for H_2O infiltration, II ('Infiltration Indicator'), will be expressed in terms of the area, A (m^2), multiplied by the infiltration quality of land (including interception and surface storage), IQ, and divided by the quality norm for infiltration, IQ_{norm}:

[A.7.13] $II = A * \dfrac{IQ}{IQ\ norm}$

So II is expressed in terms of 'equivalent m^2 of infiltration bed'.
Since the 'ultimate porosity' is 'open water', with $p = 1.0$:
3.0 'equivalent m^2 of infiltration bed' = 1 'equivalent m^2 of open water'

The marginal prevention measure is proposed to be a gravel infiltration bed. Since the costs of gravel is about 9 Euro / m^3, the eco-costs of a gravel infiltration bed with depth d is 9 x d Euro. The equation for the eco-costs of land conversion is therefore:

[A.7.14] *eco-costs of land conversion for the H_2O cycle =* Δ *II* $*$ *9* $*$ *d (Euro)*,

where Δ II is the difference between II before and after the conversion.

An alternative for a gravel infiltration bed is 'open water'.

[A.7.15] *eco-costs of land conversion for the H_2O cycle =* $\dfrac{\Delta\ II\ *\ C_{ow}}{3.0}$ *(Euro)*,

where C_{ow} is the cost per m^2 of extra open water

In normal cases, open water can be created for a C_{ow} of 18 Euro per m^2 (in an agricultural area, including the price of land), so the costs of this solution are break even with the costs of a gravel infiltration bed at $d = 0.66$ m.

In the Dutch 'waterschap' Delfland (the area between The Hague, Delft and the port of Rotterdam) a less expensive solution will be implemented: small lakes where water can be pumped in and out. The depth of these small lakes is about 2 meters. Such a measure is a factor 2/d more effective than the standard open water solution.
The costs per m^2, C_{ow}, ranges here from 11 Euro to 14 Euro, on average 12.5 Euro. For this case:

[A.7.16] *eco-costs of land conversion for the H_2O cycle =* Δ *II* $*$ *2.1* $*$ *d (Euro)*

where $d = 0.4$[64]

[64] *For Delfland the value d cannot be changed in such an area: when d is increased this will lead to subsidence and desiccation, when d is decreased it will lead to more inundation.*

Annex 7e:

Number of vascular plant species, S, and botanical value,

Q, in The Netherlands

The map of Figure A.7.4 has been derived from FLORBASE F2. This is a database with counted species of vascular plants in the wild at a national grid of 1 km^2. This database is a compilation of data from the Provinces, land owning organizations and institutes and from private persons. The map has been drawn by means of software from RIZA in the Netherlands (Ecomapper 1.0 and Demnat 2.1).
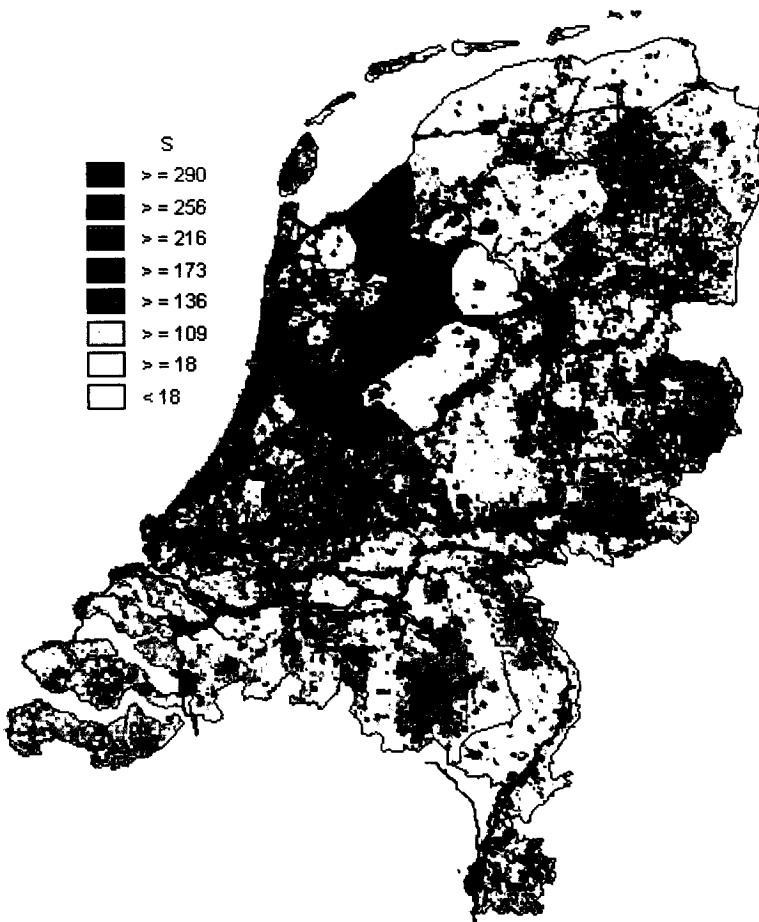
Fig. A.7.4: The species richness, S (of 1 km^2) , in The Netherlands.
   Cumulative areas (percentage of total) for S : >= 290, 5% ; >= 256, 10% ;
   >= 215, 20% ; >= 173, 35% ; >= 136, 50% ; >= 109, 60%; >= 18, 80% ; < 18 , 100%
   Note: cities have a brown colour.

The botanical value of the map of Figure A.7.5 has been calculated by Witte (Witte, 1998) from data of FLORBASE F2. The map has been drawn by means of software from RIZA in the Netherlands (Ecomapper 1.0 and Demnat 2.1)
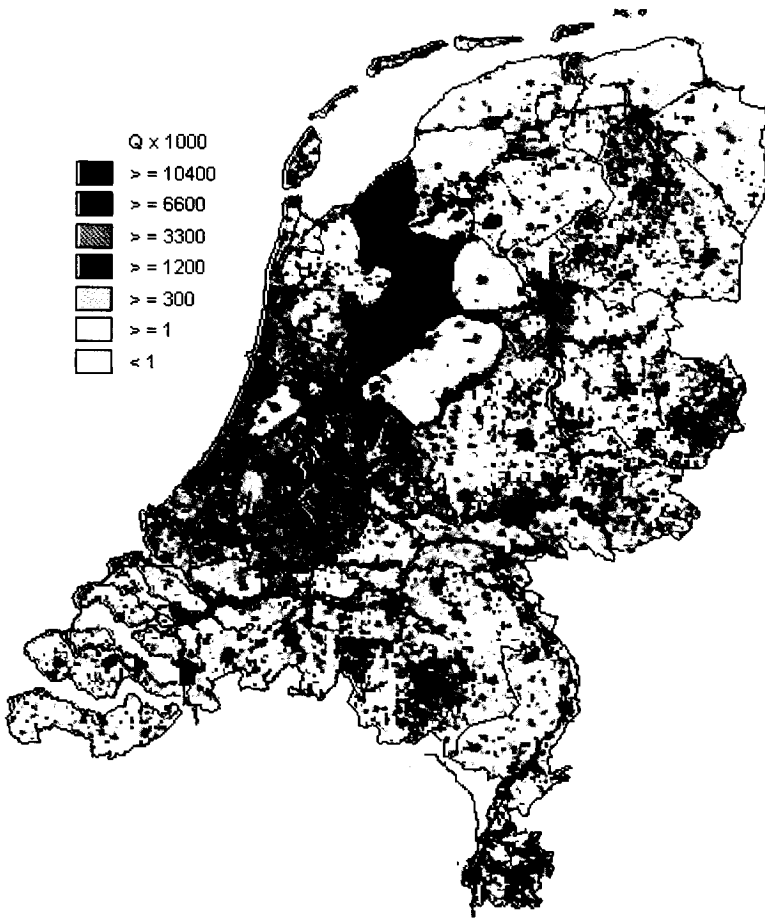
Fig. A.7.5: The botanical value, Q (of 1 km²) , in The Netherlands.
　　　　Cumulative areas (percentage of total) for Qx1000 : >= 10400, 5% ; >= 6600, 10% ;
　　　　>= 3300, 20% ; >= 1200, 35% ; >= 300, 50% ; >= 1, 60%; < 1, 100% .
　　　　Note: cities have a brown colour.

Comparison of Figure A.7.4 and Figure A.7.5 reveals that there seems to be a correlation of the data of the two methods *on a regional level* ("when the species richness S is high, the botanical value Q is also high in most of the cases").

However, when those maps are analysed in detail *on a local level*, differences between the two methods can be very significant. Details are given here for the Northern part of The Netherlands: the islands North of the Waddenzee (Terschelling, Ameland,

Schiermonnikoog, Rottemerplaat and Rottemeroog). See Figures A.7.4a and A.7.5a. It is evident that parts of these islands score low on the species richness map (Figure A.7.4a), but high on the rare ecosystems map (botanical value, Figure A.7.5a). An example is the island of Rottemerplaat, a protected area because of its high conservation value: Q is higher than 10.4, however, S is only between 136 and 109 species at one km^2!
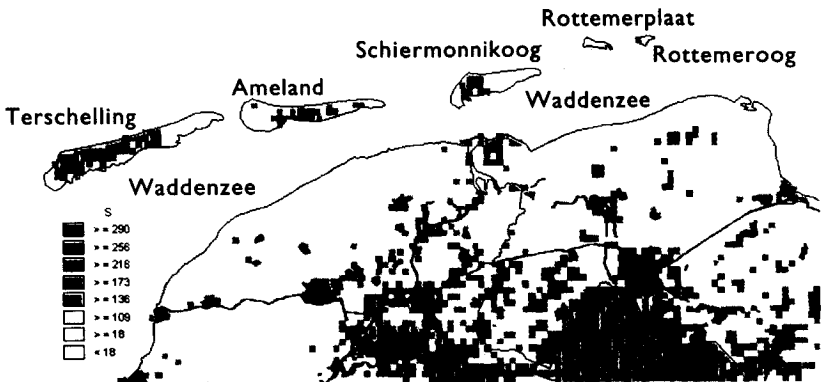
Fig. A.7.4a: The species richness, S , in the Northern part of The Netherlands.
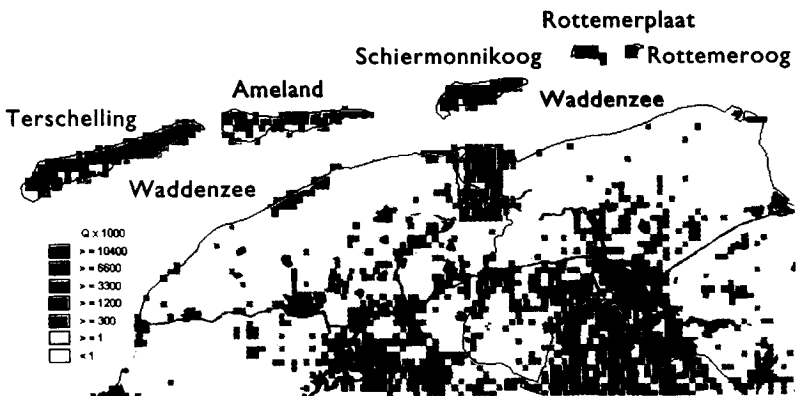
Fig. A.7.5a: The botanical value, Q , in the Northern part of The Netherlands.

Annex 7f:

Species richness of vascular plants on a global scale

The previous Annex provides the data on species richness on the national level of The Netherlands. For other European countries between 46^0 NL and 57^0 NL, Table 7.1 might be applied, but what to do in other areas of the world? Such a question is particularly of interest for the issues of land-use (land conversion) related to mining of minerals and fossil fuels and to production of wood from rainforests.

Figure A.7.6 depicts the species richness of vascular plants on a global level, on the basis of the number of species per 10,000 km^2 (Barthlott, 1998). The number of species on this map for The Netherlands are in the range of 1000 – 1500 per 10,000 km^2.

To make a preliminary estimate of the eco-costs of land conversion in other parts of the world, the following assumptions have been made:

a. $S_{10,000 \text{ km2}} = 5 * S_{ref.}$ ($S_{ref.} = 250$ for 1 km^2, when $S_{10,000 \text{ km2}} = 1250$)
b. the quality norm of The Netherlands, $S_{ref.} = 250$ (1 km^2 nature) in equation [7.1], is applied for the other areas as well (so there is one quality level of S for the whole world)
c. the eco-costs of species richness of 4 Euro per equivalent m^2 of nature, see Chapter 7.2.3, is applied for the other areas as well (that means that all areas in the world are valued at the same level, regardless of local conditions for marginal prevention or compensation costs)
d. the local number of species S before the conversion is the average number of S for the area
e. $S = 0$ after the conversion (for mining as well as production of wood from rainforests)

Applying equation [7.3] and [7.4] under the aforementioned conditions results in (see also Table 7.4):

[A.7.17] *eco-costs of species richness* $= A * 4 * S_{10,000 \text{ km2}} / (250 * 5)$ *(Euro)*

where A is the area which is disturbed by the conversion and $S_{10,000 \text{ km2}}$ is estimated from Figure A.7.6.

\

Fig. A.7.6: Global species richness: Species numbers of vascular plants (Barthlott, 1998).

Annex 8:

Diffusion of innovation.

People are, generally speaking, against 'change' in the sense of "an unexpected phe-
nomenon which comes from the outside world, and is affecting (or might affect) the
personal life". Even positive changes like job promotions go hand in hand with feelings
of doubt and even fear. Especially in management science, the management of 'change'
has got a lot of attention over the last two decades. There are two crucial aspects to
be dealt with in change management, see Figure A.8.1:
- the fact that it takes time to absorb and digest a change
- the fact that some people absorb and digest changes faster than other people
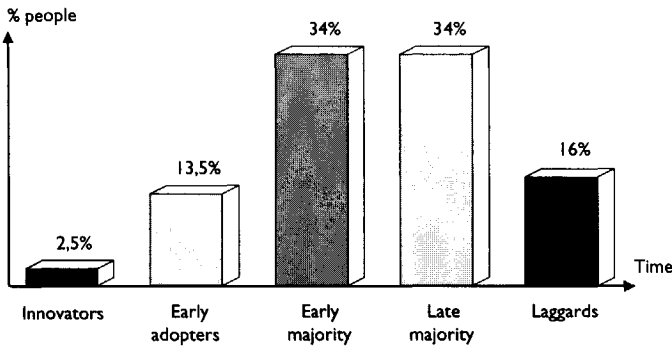
Fig. A.8.1: The positive acceptance of a change as a function of time for a group of people.

It is obvious that percentages and time depends on the magnitude of the change, but
the importance of Figure A.8.1 is the concept: for real changes and real innovations it
takes time to get it accepted.

The phenomenon of 'diffusion of innovation' has been studied by Rogers (Rogers, 1962):
"...The results of various diffusion investigations show that most individuals do not evalu-
ate an innovation on the basis of scientific studies of its consequences, although such
objective evaluations are not entirely irrelevant, especially to the very first individuals who
adopt. Instead, most people depend mostly upon a subjective evaluation that is conveyed
to them from other individuals like themselves who have previously adopted the inven-
tion..." (page 18) or,
"...Most individuals evaluate an innovation, not on the basis of scientific research by
experts, but through the subjective evaluation of near-peers who adopted the innovation
..." (page 36)

Rogers calls this the 'leader-follower model', where influential people ('opinion lead-
ers') are a crucial factor in the acceptance of a change: innovations without influential
'early adopters' will never succeed.

The consequence of Figure A.8.1 is that, when the magnitude of the innovation is too big, the innovation will never get accepted (either there are no early adopters or the time scale is too long to keep the momentum high). So some innovations need a step by step introduction planning.

In case of the Eco-cost/Value Ratio, it appeared in the workshops that this was 'a bridge too far'[65]. Hence it was decided to publish the pollution prevention costs '99 first and the eco-costs '99 thereafter, with the idea of 'economic allocation'. The fact that everything had to be strictly within the established rules of ISOs on the LCA methodology was part of the introduction policy: the theory had to be built on a solid, well accepted, basis. Only after these steps the EVR could be introduced (in the J. of Sustainable Product Design), a paper that had been written in the early start of the promotion period (it all started mid 1998 with the idea of a parameter to describe the de-linking on the basis of the WBCSD statement). The first publication (of the pollution prevention costs as a prevention based single indicator, see Section 2) in the International Journal of LCA - an opinion leading journal - triggered the process of wider, international, acceptance.

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[65] *There were, however, some innovators who immediately grasped the total concept. To name a few: Prof Han Brezet, Prof Charles Hendriks, Christine Wrisberg (CML Leiden), Almut Heinrich (Int.J.of LCA).*

Annex 9a:

An estimation of future product costs: from 'external' costs to 'internal' costs

An important aspect of our current economy is that the negative value of a product which is related to environmental damage, is not part of the costs of that product. Environmental damage is 'external' to the current cost structure. Governments will take action to reduce these 'external' costs (by regulations, tax, tradable emission rights, subsidies), which will result in higher product costs.
This annex will explain how, and to what extent, eco-costs become part of future product costs.

The concept of the 'virtual eco-costs' (in short: 'eco-costs') is slightly different from the concept of the 'external costs'. The external costs are related to *damage* to our environment. The eco-costs are related to the ('marginal') *prevention* costs, which are required to bring our economy into a state which is sustainable. What both type of costs have in common, is that they are not incorporated in the current costs of products and services (the current 'internal' costs).

The eco-costs have primarily been designed to serve as a yardstick for the environmental burden on our earth - above the level of sustainability - in terms of marginal prevention costs:
- for emissions, these marginal prevention costs are the costs of the required measures to prevent emissions above a level which is sustainable
- for energy, these marginal prevention costs are the costs to limit the use of fossil fuels to at least 50% of the current level, by applying renewable energy systems and ethanol from bio mass
- for materials, these marginal prevention costs are the costs of avoiding the use of 'virgin' materials.

In other words: the eco-costs are related to the costs to *prevent damage* to the environment.

Future product costs (in the 'what if' calculation, current prices, current production and distribution processes, excluding tax, interest and profit) can be *estimated* by taking the total eco-costs of the total life cycle and adding part of the current costs (costs for labour and recycling):
- the eco-costs of emissions, being the pollution prevention costs
- the eco-costs of energy
- the eco-costs of materials depletion (being the eco-costs for applying virgin materials)
- the eco-costs of waste disposal (for incineration and land-fill at the End of Life)
being the *total eco-costs*, PLUS, the following *part of the current costs*:
- the current costs of labour

- the current costs of recycled materials (note: total materials = recycled materials + virgin materials)

Another way to estimate the future costs is to take the current costs as a basis (excluding tax, interest, profit, and including depreciation of production assets) and add the appropriate part of the eco-costs:
- the current costs of labour
- the current costs of energy
- the current costs of materials (recycled materials + virgin materials).
being the *total current costs*, PLUS, the following *part of the eco- costs*:
- the eco-costs of emissions, being the pollution prevention costs
- the eco-costs of energy minus the current costs of energy
- the eco-costs of waste disposal (incineration and land-fill).

For a quick, rough, estimate ('guestimate') of the future product costs, *excluding* the Use phase and *excluding* the End of Life phase, one may add:
- the current total costs
PLUS
- the total eco-costs.
The reasoning behind this last guestimate of the production and distribution phase is that the material costs plus the current energy costs are in most of the cases less than 20% of the total production and distribution costs, so double counting of these elements in the equation have limited effects on the final accuracy (the accuracy of the LCA data - and therefor the resulting pollution prevention costs - often is more cumbersome).

Note that most of the cleaner production systems can lower the eco-costs more than the costs will rise!

Annex 9b:

Marketing of green commodities: Green Mountain Energy

The Green Mountain selling web site is characterized by the modern 'feel good' and 'easy going' culture. There is background information as well, but all in a positive tone.

The pricing of the product has been done very carefully: per month (not as a percentage increase). The basic idea is that you can feel good for only $4.95 per month! But for $6.95 you will feel better. Make your own choice!

You can calculate your new price when you know your current supplier and your monthly costs on electricity (will normally range between $25 and $60). You see than that the extra costs are relatively low, so you are inclined to sign up (a guarantee is given that you can cancel your choice at any moment).
You can find a page with opinions of other customers (they are all happy that they made the right choice). Join the happy few who have a life style that cares for the future!

GreenMountain.com Sign Up Now! - Netscape

http://www.greenmountain.com/electricity/signup/default.asp

Go to next page

5 select your billing option.

The whole thing should take less than ten minutes. Once you submit your completed form, we'll do all the work from there...all you have to do is feel good about the choice you've made! (It's risk-free, too -- if you ever decide to leave, we'll switch you back at no charge. We'll miss you, but we want you to be happy!)

Just select your state from the box below for your product options.

California [ ]

If you live somewhere other than California, New Jersey or Pennsylvania, you can't choose Green Mountain Energy℠ today because your state probably hasn't deregulated yet. Select your state to find out when you'll be able to choose your electricity provider and what's in the electricity you're using today.

Alabama [ ]

In New Jersey
In Pennsylvania
Sign Up Now!
Your Home
Your Business

Privacy Policy
Contact Us

GreenMountain.com - Electricity Products : Compare and Choose - Netscape

http://www.greenmountain.com/electricity/products/compare_ca.asp

Our California Power Blends

Green Mountain Energy Company offers cleaner electricity choices -- we call them power blends. They're all dramatically cleaner than typical California electricity!

1% New Renewables
99% Renewables

Eight times more renewable energy than California system power.

GOOD

5% New Renewables*
95% Renewables

BETTER

As customer demand for this blend increases, more solar panels will be built.

25% New Renewables*
75% Renewables

25% of this blend comes from three new wind turbines operating in San Gorgonio Pass.

Electricity Choices
Electricity Deregulation
How the Grid Works
Sources of Electricity
In Your State
How You Can Save Energy
Why Choose Green Mountain Energy℠
Our Environmental Results
Our Electricity
New Renewables
Green-e Verification
What People Are Saying
Meet Us
Our Products and Prices
In California
In New Jersey
In Pennsylvania
Sign Up Now!
Your Home
Your Business

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Annex 10:

A methodology to determine the eco-costs of noise.

Introduction.

In relation to the fact that this thesis is providing a decision support tool for product designers, business managers, and governmental authorities, the question was raised whether or not it is possible to determine the '(virtual) eco-costs of noise', based on the principle of the marginal prevention costs.
This Annex shows an outline of the methodology to determine such an indicator for cars (within the framework of normal LCAs) and for roads (within the framework of urban planning policy), and provides a preliminary estimate on the eco-costs of noise for those subjects.

Apart from noise-induced hearing losses, cased by specific exposures to extreme high noise levels, annoyance - caused by medium and low noise exposures in our daily lives - is getting more and more important. These low and medium noise levels are disturbing our lives to a level which becomes quite unacceptable. In The Netherlands, about 40% of the inhabitants claim that they are 'seriously disturbed' by one or more of the following sources of noise (1995, see NMP3):
- road traffic (25%)[66]
- military aviation (10%)
- civil aviation (5 %)
- industry (6%)
- rail (2%)
- noise from neighbours (13%).

The dose-effect relationship with respect of annoyance is quite complicated, since it is not only related to the quite complex characteristics of noise (loudness, frequencies, variation in time), but also related to how it is perceived (music, an aircraft, a pneumatic hammer) in which mental state. Figure A.10.1. shows the percentage of 'seriously disturbed' persons as a function of the noise level, Ldn[67], for some sources of noise (Passchier-Vermeer, 1996).

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[66] *With regard to road traffic, 26% of the Dutch houses are exposed to a sound level which is higher that the governmental norm for it, 55 dB(A). The spread of this percentage over the regions of the country is only 2%. (De Jong et al., 1996)*

[67] *There are several ways to define the 'average noise level', L_{Aeq} - in dB(A) - , over a period of time:*

-L_{dn} , which is for a period of 24 hours ('day and night'), where the levels in the night period from 22.00 hours to 7.00 hours are increased by 10 dB(A).

-L_{etm} , which is the maximum of the average level of either the day, or the evening (19.00 – 23.00 hours) + 5 dB(A), or the night (23.00 – 7.00 hours) + 10 dB(A).

-L_{Ax} (or SEL), which is the energy (in dB) for short, individual, noise exposures (maximum a few seconds), normalized in a short noise exposure of 1 second.
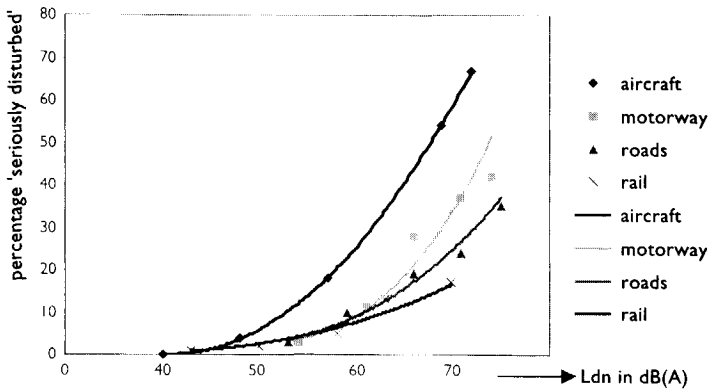
Fig. A.10.1: Percentage of 'seriously disturbed' persons as a function of the noise level, Ldn , for some sources of noise (Passchier-Vermeer, 1996).

The eco-costs of noise (of a car)

Since road traffic is causing the major annoyance in The Netherlands, and since cars are the main source of it, it makes sense to determine the 'eco-costs of noise' of a car. It is quite impossible to determine the damage based costs of noise per car, because of:
- the non-linearities in the dosis-effect relationships (when one car has a sound level of 70 dB(A), two cars have a sound level of 73 dB(A), leading to an increased level of disturbance via the curves of Figure A.10.1.)
- the complex relationship between 'emission' and 'immission' (Ref. Annex 2a), based on a specific place and a specific time
- it is impossible to weigh the different levels of disturbances and monetarize the related costs.

A methodology based on prevention costs, however, is quite feasible if the norms for maximum (sustainable) noise levels can be set. This is illustrated for the case of cars. The methodology applies as well to other sources of noise which are spread random-ly over the country, like trucks, and might be applied to aeroplanes in relation to a certain airport region.

The norm is based on the assumption that "a person's sleep at night is not disturbed by a car passing by on the street (a small window of the bedroom is partly open to allow for fresh air)":
- medical research shows that the state of sleep (REM, NREM-1,2,3,4) is changed above L_{Ax} = 35 dB(A) , (Passchier-Vermeer, 1996)
- the corresponding outside sound level will be 15 dB(A) higher, so 50 dB(A).

The consequences for the car (and the road) are then:
- the noise level of the car at 50 km/hr: 60 dB(A), at a distance of 7.5 m

- the road surface is double layer porous asphalt concrete (Dutch: ZOAB), reducing the sound level by 4 dB(A) at 50 km/hr (6 dB(A) at 100 km/hr); this improvement is achieved by a reduction of the noise of the tyres and by absorption of the noise underneath the car
- the distance car-window is 15 m, resulting in a reduction of sound level of 6 dB(A)
- so the resulting sound level in the open window is 60 − 4 − 6 = 50 dB(A)[68].

The BAT (best available technology) for modern cars at 50 km/hr is 68 dB(A)[69]. So the technology gap is 8 dB(A), which is equivalent to a reduction of sound energy to 15% of the original value. Although this gap seems relatively small, it is not easy to bridge: new engine systems are required.

What is lacking to arrive at the related eco-costs of noise is a list of measures, with costs, to bridge the gap. So further research on this subject is required by specialists.

A first guess of the eco-costs of noise can be made though, applying the following assumptions:
- the future cars with electric engine systems can meet the 8 dB(A) reduction requirement
- the future cars with electric engine systems will cost 33% more than current cars with a conventional petrol motor
- the benchmark is a middle class car with conventional petrol motor, price 24,000 Euro.

Then the eco-costs of noise (for a car) are 1000 Euro per dB(A), above the level of 60 dB(A).

The eco-costs of noise (for a road)

In relation to urban and rural planning, it makes sense to determine the eco-costs of noise of a road (motor way). In such a case the road is taken as the object, rather than the cars on it.

For the norm, we take basically the same norm of the previous chapter: *a person's sleep at night is not disturbed by cars passing by on the street (a small window of the bedroom is partly open to allow for fresh air)*". The difference with the previous chapter is that we take here all the cars on that road, and take the average noise level during the critical period (22.00 − 2.00 hours)[70]. The norm is specified as:

[68] *At a background noise level of 50 dB(A), a conversation can be held at 'normal speech level' (Passchier-Vermeer, 1996)*
[69] *Most modern cars are 1, 2, or 3 dB(A) worth, see www.xs4all.nl/~rigolett/ENGELS/typetest/car1.htm*
[70] *22.00- 2.00 hours seems to be the most critical period: there are still a lot of cars on the road, combined with the fact that the first 2.5 hours of our sleeping cycle seems to be quite important for the daily performance of our brain.*

- the norm of the WHO with regard to sleep disturbance during the night: L_{Aeq} = 30 dB(A), inside (B.Berglund et al., 1999). Note that we apply here the L_{Aeq} instead of the L_{Ax}
- he norm of the WHO with regard to sleep disturbance during the night: L_{Aeq} = 45 dB(A), outside, (B.Berglund et al., 1999) taking into account a small window open for fresh air.

The consequences for the road, double layer porous asphalt concrete, are then (situations which result in LAeq = 45 dB(A)[71]):
- 500 cars per hour (the sum of both directions) at a distance of 200 m.
- 150 cars per hour (the sum of both directions) at a distance of 100 m.

For a 2x2-lane motorway, the aforementioned densities of traffic are rather low for roads near big cities on late Saturday evenings. A traffic density of 1500 cars is not uncommon, leading to LAeq = 55 dB(A) at a distance of 100m. Therefore a prevention measure has to be taken: a sound screen. Recent studies show (E. Salomons, 2000), that a maximum reduction of L_{Aeq} = 10 dB(A) can be expected by such a prevention measure.

The prevention costs of such a screen (height 5-6 m, aluminium, partly transparent, architectural design) at both sides of the road is estimated at 6000 Euro/m (recent projects: A16 at Zwijndrecht, A20 at Rotterdam).

Therefore, the eco-costs of noise (for a road) are estimated at 600 Euro/m per dB(A), above the level of L_{Aeq} = 45 dB(A) at 22.00 – 2.00 hours.

Note a. The above calculations are well in line with the Dutch law on noise-disturbance.
Note b. At day time, the maximum traffic density on a 2x2-lane motorway is estimated at 8000 vehicles; the sound level at 100m - as well as 'shaded' area between the noise screen and this point - is 52 dB(A), which is low enough to accommodate a city-park or shopping area.
Note c. Since a screen has a maximum sound level reduction of 10 dB(A), extra prevention measures have to be taken when the traffic density at night is higher. Temporary reduction of the speed limit during those busy hours is rather effective: 1500 cars per hour at 100 km/h generate the same noise level as 4000 cars per hour at 75 km/h.

The eco-costs of noise in relation to land use

It is obvious that the aforementioned noise disturbance should be prevented at the source, i.e. the cars. But that will take probably more than one decade. In the mean

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[71] *Calculations made by a simple (in terms of sophistication) calculation program, free available at www.xs4all.nl/~rigolett/ENGELS/vlgcalc.htm*

time our society has to deal with the serious problems of noise disturbance by roads.

Noise disturbance by roads can be regarded as a 'second order effect' of land use: the construction of a road effects the quality of land of a bigger area than the road itself. The extra strip of land of 200 m at each side of an 2x2-lane motorway (as it is required by the Dutch law on noise-disturbance) seems to be not in line with the prevention aim in terms of land use (enhance the density of land-use in urban areas). It is obvious that, in proper urban planning, the architectural design of a noise screen has to go hand in hand with the architectural design of the area behind it, in relation to other functions in the cities (parks, shopping centres, parking garages, etc.).

In the case of the A4 between Delft and Schiedam (Chapter 7.7), the eco-costs of noise should be added as a second order effect of the construction of this road. For a traffic density at night of 1500 cars/hr, the eco-costs of noise are 6000 Euro/m. This adds 21 million Euro to the eco-costs of land-conversion for the total length of 3.5 km. Innovative solutions have already been proposed (De Ridder, 1999) for the part of the road where it passes the city of Schiedam, but innovative solutions for the area between Delft and Schiedam should be created as well (e.g. in combination with a park). Noise screens with an open land-strip behind it are definitely not the only solution here!

Tables

Table 2.1 Characterisation factors, mass based (Goedkoop, 1995).

Substance		Weighing factor	Substance		Weighing factor
Global warming			**Carciogenics**		
CO2	Air	1	PAH	Air	In summer smog
N2O	Air	270	Benzo[a]pyrene	Air	1
Dichloromethane	Air	15	As	Air	0.044
HFD-125	Air	3400	CxHy aromatic	Air	0.000011
HFC-134a	Air	1200	Benzene	Air	In summer smog
HFC-143a	Air	3800	Fluoranthene	Air	1
HFC-152a	Air	150	Ni	Air	0.44
Methane	Air	In summer smog	Cr (6+)	Air	0.44
Trichloromethane	Air	25	Tar	Air	0.000011
Acidification			ethylbenzene	Air	0.000011
Nox	Air	0.7	**Summer Smog**		
SO2	Air	1	CxHy	Air	0.398
HCL	Air	0.88	Phthalic acid anhydride	Air	0.761
HF	Air	1.6	Terpentine	Air	0.377
Ammonia	Air	1.88	Aldehydes	Air	0.443
NO	Air	1.07	PAH	Air	0.761
SOx	Air	1	Methyl mercaptane	Air	0.377
NO2	Air	0.7	Ethanol	Air	0.268
Eutrophication			Vinylacetate	Air	0.223
Nox	Air	In acidification	Crude oil	Air	0.398
Ammonia	Air	In acidification	Ethylene glycol	Air	0.196
NO	Air	In acidification	Ethylene oxide	Air	0.377
NO2	Air	In acidification	Caprolactam	Air	0.761
Nitrates	Air	0.42	Viny;chloride	Air	0.021
Phosphate	Air	1	Hydroxy compounds	Air	0.377
COD	Water	0.022	Ketones	Air	0.326
NH3	Water	0.33	Diethyl ether	Air	0.398
Phosphate	Water	1	Tetrachloromethane	Air	0.021
NH4+	Water	0.33	1,1,1-trichoroethane	Air	0.021
Ptot	Water	3.06	Dichloromethane	Air	0.01
Ntot	Water	0.42	Methane	Air	0.007
Heavy Metals			Hexaclorobiphenyl	Air	0.761
Hg	Air	1	Petrol	Air	0.398
Pb	Air	1	Alcohols	Air	0.196
Cd	Air	50	CxHy aliphatic	Air	0.398
Cadnium oxyde	Air	50	CxHy chloro	Air	0.021
Heavy metals	Air	1	CxHy aromatic	Air	0.761
Mn	Air	1	Diphenyl	Air	0.761
Pb	Water	1	Isopropanol	Air	0.196
Hg	Water	10	Benzene	Air	0.189
Cd	Water	3	Ethene	Air	1
Sb	Water	2	Propane	Air	0.42
Cr	Water	0.2	Propene	Air	1.03
Cu	Water	0.005	Styrene	Air	0.761
Mo	Water	0.14	Toluene	Air	0.563
As	Water	1	Xylene	Air	0.85
Ba	Water	0.14	Phenl	Air	0.761
Ni	Water	0.5	VOC	Air	0.398
Mn	Water	0.02	Methyl ethyl ketone	Air	0.473
B	Water	0.03	Formaldehyde	Air	0.421
Winter Smog			Pentane	Air	0.408
Dust (SPM)	Air	1	Non methane VOC	Air	0.416
SO2	Air	In acidification	Acetone	Air	0.178
Carbon black	Air	1	Trichloroethene	Air	0.066
Soot	Air	1	Chlorophenols	Air	0.761
Iron dust	Air	1	Acetylene	Air	0.168
			Propionaldehyde, propanal	Air	0.603
			Naphtalene	Air	0.761
			1,2-dichloroethane	Air	0.021

Table 2.2 List of measures for reduction of greenhouse gases in order of rising costs.
(West European price level, 1998) (Beeldman, 1998).

	Costs (Euro / 1000 kg CO_2 equivalent)	Short description
1	0 (or negative)	1999 tax increase on petrol
2	0 (or negative)	2003 tax increase on petrol
3	0 (or negative)	Greening of taxes on cars (1)
4	0 (or negative)	Less fuel consumption cars 1999
5	0 (or negative)	Less fuel consumption cars 2003
6	0 (or negative)	Energy campaign on cars
7	0 (or negative)	Differentiating tax on new cars
8	0 (or negative)	Differentiating tax on existing cars
9	0 (or negative)	Increase of tire pressure
10	0 (or negative)	Stringent control on current speed max.
11	0 (or negative)	Energy savings of domestic appliances
12	0 (or negative)	Cruise control, etc. in cars
13	0 (or negative)	Max. speed trucks 80 km/hr , stringent control
14	0 (or negative)	Max. speed cars 100 km/hr , stringent control
15	0 (or negative)	Energy savings in domestic houses
16	0 (or negative)	Existing level of nuclear power
17	0 (or negative)	Energy savings in industry
18	0 (or negative)	Energy savings in farms
19	0 (or negative)	Commuting more by car sharing or by public transport
20	0 (or negative)	More public transport for short distances
21	0	PFCs reduction in the aluminium industry
22	0.2	HFC reduction by means of afterburners in industry
23	1.6	N_2O reduction in nitric acid production
24	4.1	Biochemical reduction of methane emissions at organic waste
25	4.5	Oxidation of methane at organic waste
26	9	Early closure of coal fired power plants
27	9	Replacing HFCs for coolants
28	11	Reduction methane emissions at gas fields
29	11	Replacing HFCs in hard foam
30	11	Replacing HFCs for aerosols
31	11	Recycling of HFCs for coolants
32	11	Reduction of HFC emissions in production of "closed" foam
33	11	Reduction SF_6 emissions in chips industry
34	11	Reduction SF_6 emissions from power switches
35	20	Bio mass for industrial heat and power plants
36	20	Carbon black for heat and power plants
37	20	CO_2 storage (underground) at refineries and ammonia production
38	25 – 110	Emission reduction in agriculture
39	22	Replacement of coal by gas in power plants
40	35	District heating near power plants
41	40	Reduction of HFC leakages
42	50	Reduction of methane emissions by manure processing
43	55	Gassification of biomass
44	57	CO_2 storage at new gas fired power plants
45	60	Energy savings by domestic heat pumps
46	65 – 155	Domestic solar heating (boiler) systems
47	65	Import of bio mass for industrial heat and power plants
48	70	Certificates for industry
49	70	NO_2 reductions from traffic
50	70	CO_2 storage at coal fired power plants
51	80	Nuclear power plants, new (this measure is skipped for obvious reasons)
52	90	CO_2 storage existing gas fired power plants
53	110	Energy savings in existing industrial buildings
54	40 – 130	Wind energy, on shore
55	140	Biofuels for cars
56	155	Expansion Dutch forests
57	180 –195	Domestic 'low energy' houses
58	100 – 230	Wind energy, off shore
59	145 – 245	'Low energy' buildings (new) in the industry
60	190 – 470	Further expansion Dutch forests
61	660	Photo Electric cells

Table 2.3 An example of the calculation of the pollution prevention costs '99.
Wood based chlorine free bleached white printing paper, quantity 1 kg.
(Data from BUWAL Oekobilanz von Packstoffen, 1990, Bern)

column 1	2	3	4	5	6	7	8
pollutant	class	amount (kg)	characterization factor	3 × 4 "kg equ."	poll. prev. costs (euro/kg)	5 × 6 poll. prev. costs '99 (euro)	= sum of 7 Total poll. prev. costs '99
ammonia	acidification	3.63E-06	1.88	6.82E-06			(euro)
HF	acidification	1.20E-08	1.6	1.92E-08			
NO_x	acidification	5.47E-03	0.7	3.83E-03			
SO_2	acidification	1.22E-02	1	1.22E-02			
			subtotal:	1.60E-02	6.4	1.03E-01	
ammonia	eutrophication	3.63E-06	in acidification				
NO_x	eutrophication	5.47E-03	in acidification				
COD	eutrophication	4.46E-02	0.022	9.81E-04			
NH_3	eutrophication	1.03E-06	0.33	3.40E-07			
			subtotal:	9.82E-04	3.05	2.99E-03	
CO_2	greenhouse ef.	1.61	1	1.61E+00			
N_2O	greenhouse ef.	3.59E-04	270	9.69E-02			
			subtotal:	1.71E+00	0.114	1.95E-01	
Hg in air	heavy metals	1.90E-08	1	1.90E-08			
Hg in water	heavy metals	1.00E-09	10	1.00E-08			
			subtotal:	2.90E-08	680	1.97E-05	
aldehydes	summer smog	1.02E-05	0.443/0.398=1.113	1.14E-05			
C_xH_y	summer smog	6.98E-03	0.398/0.398= 1.0	6.98E-03			
methyl mercaptane	summer smog	1.85E-04	0.377/0.398=0.947	1.75E-04			
			subtotal:	7.16E-03	50	3.58E-01	
dust (SPM)	winter smog	4.57E-03	1	4.57E-03			
SO_2	winter smog	1.22E-02	in acidification				
			subtotal:	4.57E-03	12.3	5.62E-02	
			Total pollution prevention costs '99, 1 kg paper:				**7.14E-01**

Table 2.4 Classification in some models which are used in product design.

Classes	Eco-costs model Vogtländer	Eco-indicator '95	Eco-indicator '99	EPS[72]	NSAEL	SETAC
Eutrofication	+	+	+		+	+
Acidification	+	+	+		+	+
Ozone layer		+	+		+	+
Carcinogenics	+	+	+			
Global warming	+	+			+	+
Heavy metals	+	+				
Winter smog	+	+				
Summer smog	+	+				+
Pesticides		+				
Noise	(+)					+
Smell						+
Radiation						+
Health			+	+		
Human toxicity					+	+
Respiration				+		
Depletion materials	+		+	+		
Loss of agric. production	+			+		
Damage ecosystems			+			
Ecotoxicity			+			+
Species richness	+			+		
Scenic beauty	+					
Casualties						+
Aesthetic value				+		
Econ. value	+					

References:
Eco-costs: (Section 3)
Eco-indicator '95: (Goedkoop, 1995)
Eco-indicator '98: (Goedkoop et al., 1998)
EPS: (Steen, 1996)
NSAEL: (Kortman et al., 1994)
SETAC: www.ecomed.de/journals/lca/village/commWIA2.htm

[72] The EPS model deals directly with 'safeguard objects' without classification and characterization and determines the relative importance of the ecological burden by determining the 'willingness to pay' to avoid the damage.

Table 3.1 The virtual pollution prevention costs '99 of materials (including pollution from energy).
Based on LCA's from (M. Goedkoop, 1995) and marginal prevention costs (Section 2).

Materials	Virtual pollution prevention costs '99 (Euro/kg)
Aluminium	2.64
Secondary aluminium	0.44
Copper	3.96
Secondary copper	1.14
Stainless steel	1.15
Secondary steel	0.40
Steel, (general BUWAL data)	1.48
Steel, (Dutch manufacturing)	0.42
Steel plate	1.52
Glass	0.29
Glass wool	0.55
Ceramics	0.22
Paper board (BUWAL data)	0.36
Paper board (Dutch manufacturing)	0.09
Wood	0.12
Cellulose board	1.22
Paper	0.71
Recycled paper (BUWAL data)	0.39
Recycled paper (FEFCO data)	0.10
Concrete (reinforcing 70 kg/m^2)	0.20
Acylonitril-butadiene-styrene	4.00
High density polyethylene	1.26
High impact polystyrene	2.00
Low density polyethylene	1.33
Polyamide	5.28
Polyethylene tereftalat (PET)	2.52
Polypropylene	0.92
PPE/PS	1.25
Polystyrene hard foam	5.71
PUR	1.02
PVC	1.35
Rubber (natural)	1.23
Stone wool	0.56

Table 3.2. The eco-costs of energy , and the corresponding EVR for energy.
Costs of sustainable energy based on MARKAL data (Gielen et al., 1998), (ECN, 1998).

Category	Current prices (Euro/GJ)	Main sustainable energy source	Eco-costs of energy (Euro/GJ)	EVR
Industrial heat	2.80	Biomass	5.00	1.80
Diesel for trucks in EC, 1998[1])	15.60	Ethanol from biomass	28.70	1.84
Diesel for trucks in EC, 2000[2])	21.50	Ethanol from biomass	28.70	1.33
Electricity (industry)	12.70	Biomass +wind+hydro	19.55	1.54
Electricity (domestic)	13– 26	Biomass +wind+hydro	19.6 – 32.8	1.5-1.25
Petrol for cars in EC, 1998[1])	22.70	Ethanol from biomass	35.80	1.57
Petrol for cars in EC, 2000[2])	29.20	Ethanol from biomass	35.80	1.23
Domestic heating	6.15	Suncollectors+heatpumps	9.70	1.58

[1] Approximate price for the Netherlands, Germany, France, Italy, summer 1998, excl. VAT (Brent oil $12.50 per barrel)

[2] Approximate price for the Netherlands, Germany, France, Italy, summer 2000, excl. VAT (Brent oil $32.00 per barrel)

Table 3.3 The materials depletion costs.

Materials	"Materials depletion costs" (Euro/kg)	Materials and energy	"Mat. depl. costs" (Euro/kg) and "Energy dep. costs"
METALS (in ore)		METALS (in ore)	
Aluminium	1.4	Tin	9
Antimony	2.7	Titanium	9
Arsenic	1.0	Tungsten	0.06
Beryllium	700	Vanadium	22
Bismuth	8	Zinc	1.2
Cadmium	2.0	Zirconium	22
Calcium	4.5		
Cesium	1.5	MATERIALS	
Chromium	8.0		
Cobalt	45	Secondary aluminium	0 (Euro/kg)
Columbium (Niobium)	7	Secondary copper	0 (Euro/kg)
Copper	0.2	Secondary steel	0 (Euro/kg)
Gallium	400	Waste paper	0 (Euro/kg)
Germanium	1,200		
Gold	10,000	Bauxite	0.4 (Euro/kg)
Hafnium	200	Iron ore	0.05 (Euro/kg)
Indium	300	Manganese ore	0.0025 (Euro/kg)
Iron	0.1		
Lead	0.8	Wood (planted trees)	0 (Euro/kg)
Lithium	80	Wood (rain forest)	1 (Euro/kg)
Magnesium	3.5		
Manganese	0.005	Plastics	0.6 (Euro/kg)
Mercury	6		
Molybdenum	5	Oil feedstock	0.6 (Euro/kg)
Nickel	7	Natural gas feedstock	0.6 (Euro/kg)
Platinum	12,800	Natural gas	0.4 (Euro/m3)
Palladium	4,800		
Iridium	6,000	ENERGY sources	
Osmium	13,000		
Rhodium	16,000	Electricity	0.07 (Euro/kWh)
Ruthenium	1,500	Electricity	19.60 (Euro/GJ)
Rhenium	1,000		
Rubidium	750	Diesel for trucks and cars	1.03 (Euro/litre)
Selenium	9	Diesel for trucks and cars	28.70 (Euro/GJ)
Silicon	1.5	Petrol for cars	1.50 (Euro/litre)
Silver	160	Petrol for cars	35.80 (Euro/litre)
Tantalum	70		
Tellurium	50	Domestic heating	9.70 (Euro/GJ)
Thallium	20	Industrial heat	5.00 (Euro/GJ)
Thorium	40		

Derived from: Metal prices in the USA, Mineral Information Team, USGS,
www.minerals.usgs.gov/minerals/pubs/metal_prices ,
(average market value for the period 1988 – 1998, with trend were applicable)

Table 3.4. Summary of the eco-costs of an office building (excluding energy during the use phase !), example.

Summary description of an office building (typical)	Eco-costs (Euro/m²)	Life time (years)	Eco-costs (Euro/m² /annum)	
Main materials for construction:				
- concrete, 300 kg/ m² (eco-costs 0.2 Euro/kg, see Table 1)	60	40	1.5	
- steel, 50 kg/m² (eco-costs 1.8 Euro/kg, see Table 1 and 3)	90	40	2.25	
- miscellaneous materials. 50 kg/m² (glas, wood, PVC, etc.)	30	40	0.75	
- building activity (energy. etc.)	40	40	1.00	
Subtotal construction building structure		220	40	5.50
Building systems (elevators, heating, electrical, water, etc.)		60	20	3.00
Interior (painting, decorating, furniture,etc.)		120	15	8.00
Computer system (one screen per employee at 33 m2)		9	3	3.00
Maintenance of building and building systems per year		3	-	3.00
End of Life:				
Demolition + transport of materials at End of Life	20	40	0.50	
Disposal of construction waste (eco-costs 0.1 Euro/kg)	40	40	1.00	
Subtotal End of Life		60		1.50
Total				**24**

Table 3.5 An example of using the EVR model for economic allocation in a transport chain.The functional unit is defined as: "transport of 25,000 litre net volume of tomatoes from Holland to Frankfurt"
(Example of volume based transport in corrugated board boxes, full truck load, truck empty back. See for a detailed analysis of this transport function Section 6)

	Chain element	LCA subsystem	Value (Euro)	EVR '99	Eco-costs (Euro)
Example of	Packaging	(one way boxes)	47	0.15	7.0
the value	Transport	Truck, fuel, road	38	0.72	27.4
structure	Storage	Building	11	0.34	3.7
of transport		Handling	2	0.33	0.7
(simplified)	End-of-life	(packaging)	2	0	0
Total Chain			**100**		**38.8**

Table 3.6. Virtual eco-costs '99 for a warehouse, 920 pallets (900 m2, 10 meters high). Calculation according to the classical approach of the LCA method, excl. Use phase and EoL phase

	greenhouse kg CO₂ equ	acidification kg SO₄ equ	eutroph. kg PO₄ eq	hv. metals kg Pb equ	carcin kg B(a)P eq	s. smog kg VOCeq	w.smog kg SPM eq	Eco-costs '99 (Euro)
Concrete, reinforced, 551200kg	59629	484.6	51.07	0.46	0.015	54	6490	99459
Fe360, 51000kg	58271	708.1	63.65	1.05	0.035	79	427	36592
steel sheet. 22000kg	38585	214.4	12.09	0.12	0.021	670	176	47976
PS, 40kg	164	0.2	0.04	0	0	1	0	71
PS foaming, 40kg	222	3.3	0.07	0	0.001	2	0	152
steel transforming, 22000kg	1449	9.6	0.44	0.01	0.001	1	7	367
steel transforming, 51000kg	3475	22.3	1.03	0.03	0.002	2	17	864
Eco-costs of contractors and suppliers (guestimate)								72000
Total in kg equivalent:	161798	1442.9	128.39	1.67	0.075	809	7117	
Eco-costs '99 (Euro)								257481

Table 3.7 Virtual eco-costs '99 for a warehouse, 920 pallets (900 m^2, 10 meters high).
Calculation according to a standard cost estimate system and the EVR model.
The costs estimate is from the DACE database on costs (DACE is the Dutch Association of
Cost Engineers). The EVR has been based on LCA data.

Warehouse	Value Euro / m^2	EVR	Eco-costs Euro / m^2	Ecokosten Euro / 900 m^2
floor , reinforced concrete, 300 mm thick	140	0.8	112	100473
steel structure	80	0.7	56	50114
foundation of steel structure	15	0.8	12	11127
roof, steel+thermal insulation	75	0.4	30	26836
Cladding+ insulation (surface.=1.3xfloor area)	95	0.4	38	34036
Lighting, heating, sprinklers, etc.	45	0.3	14	12027
Total	**450**	**0.58**	**261**	**234614**

Table 3.8 The eco- costs of industrial activities, and the corresponding EVR·
Note: the Table is based on Added Value and emissions of the sector itself,
excluding sourced materials

INDUSTRY (CBI-code)	POLL.PREV. COSTS '99 (10^6 Euro)	ECO- COSTS '99 (10^6 Euro)	ADDED VALUE (10^6 Euro)	EVR
Food industry (15,16)	1030	1430	9030	0.16
Textile- en clothing-industr.(17,18)	95	204	838	0.24
Leather industry (19)	26	36	81	0.44
Wood industry (20)	109	159	415	0.38
Paper industry. (21)	498	712	1390	0.51
Printing industry (22)	1000	1400	3400	0.41
Oil industry (23)	2950	3220	890	3.61
Basic chemicals ind. (2412-2414)	2950	3870	4680	0.83
Fertiliser industry. (2415)	306	incl. basic chem	incl. basic chem	incl. basic chem
Agriculture chemicals (242)	19	25	44	0.56
Coatings- and ink-industry (243)	47	96	420	0.23
Pharmaceutical industry (244)	95	not available	not available	not available
Detergents industry (245)	17	52	307	0.17
Other Chemicals (246)	100	not available	not available	not available
Fibre industry (247)	246	not available	not available	not available
Rubber industry (251)	35	557	1330	0.43
Converting industry plastics(252)	320	incl. in rubber	incl. in rubber	incl. in rubber
Building materials (26)	711	936	1710	0.55
Basic metals industry (27,231)	2130	2380	1840	1.29
Metal products industry (28)	456	797	2770	0.29
Machine- en equipment ind.(29)	106	456	3060	0.15
Electrical industry (30-32)	429	1000	4520	0.22
Automotive industry (34)	518	1090	1710	0.64
Shipyards (351)	256	incl. auto ind.	incl. auto ind.	incl. auto ind.
Instrument- and optical ind.(331)	13	50	312	0.16

Table 4.1. The 'waste treatment levy'('verwijderingsbijdrage') in The Netherlands.

	Euro		Euro
Televisions	11.34	Electric garden tools	4.08
Portable radios, cassette players, etc	1.13	VCRs	6.81
Fan	3.40	Domestic appliances	1.13
Washing machines	9.08	Electric tools	1.82
Electric music instruments	6.81	Freezers and refrigerators	18.15
Electric guitars	2.27	Audio appliances	2.27
Sewing machines	9.08	Grill, extractor fan, microwave	6.81
Central heating boilers	4.54	Car tyres	2.04

Table 4.2. Summary of the eco-costs of an office building (excluding energy during the use phase !).
Note: this office building is the same as the office building of the example of Table 3.4

Summary description of an office building (typical)	Investment (Euro/m^2)	Life time (years)	Depreciation (Euro per m^2 per year)	EVR	Eco-costs (Euro per m^2 per year)
Subtotal construction building structure	630	40	15.75	0.35	5.50
Building systems (elevators, heating, electrical, etc.)	170	20	8.50	0.35	3.00
Interior (painting, decorating, furniture,etc.)	340	15	22.70	0.35	8.00
Computer system (one screen per employee at 33 m^2)	30	3	10	0.30	3.00
Maintenance of building and building systems per year		-	15	0.20	3.00
End of Life:					
Demolition + transport of materials at End of Life	40	40	1	0.50	0.50
Disposal of construction waste (eco-costs 0.1 Euro/kg)	40	40	1	1.00	1.00
Subtotal End of Life					1.50
Total					**24**

Table 4.3: The eco-benefit (in Euro) of recycling of the steel of the steel structure
and re-use of the floor slab of a warehouse.

Note: all values in Euro	0% recycled	95% recycled or re-use	Eco-benefit
EoL of Old Building			
Eco-costs of Land Fill	62,424	3,121	59,303
Eco-costs of transport	624	624	0
Total eco-costs EoL	63,048	3,745	
		Total eco-benefit EoL	59,303
Materials for new building			
Eco-costs of steel	84,568	31,862	52,706
Eco-costs of concrete floor	99,459	4,973	94,486
Total eco-costs materials	184,027	36,835	
		Total net eco-benefit materials	147,192
		Total net eco-benefit	**206,495**

Simplified example of a warehouse of 900 m$_2$, 10 m high, 920 pallets. floor slab 551,200 kg
reinforced concrete, steel structure 51,000kg, steel sheets for roof and cladding 22,000kg.
For details see Tables 3.6, 3.7 and 6.17 through 6.21

Table 5.1. Eco-costs of Components 28" TV.

	Eco-costs (Euro)
CRT	35.30
Speakers	10.20
Enclosure	11.80
Chassis	44.30
Packaging	3.40
Total	106.00

Table 5.2. Eco-costs of the production and distribution chain of a 28" TV (tentative).

		ΔValue (Euro)	Value (Euro)	Δ Eco-costs (Euro)	Eco-costs (Euro)	EVR
1	Components	200	200	106	106	0.53
2	Assembly	150	350	33	139	0.22
3	Distribution	50	400	36	175	0.72
4	Advertising, etc	50	450	10	185	0.20
5	Retail	225	675	23	208	0.10
	Total	675		208		0.31

Table 5.3. The "Total costs of Ownership", TCO, and the "Total Eco-Costs of Ownership", TECO, of a standard 28" TV and a "low energy" 28" TV, for two consumer markets.

All prices in Euro	Watching 6 hours per day (average in a year)			
	standard 28" TV		*"low energy" 28" TV*	
	Value (costs)	Eco-costs	Value (costs)	Eco-costs
Purchase	675	208	776 (+15%)	239 (+15%)
Energy "watching"	174	239	130 (-25%)	179 (-25%)
Energy "stand by"	13	18	10 (-25%)	13 (-25%)
"End of Life"	30	3	30	3
TCO and TECO	**892**	**468**	**912 (+2%)**	**434 (-7%)**

All prices in Euro	Watching 1.5 hour per day (average in a year)			
	standard 28" TV		*"low energy" 28" TV*	
	Value (costs)	Eco-costs	Value (costs)	Eco-costs
Purchase	675	208	776 (+15%)	239 (+15%)
Energy "watching"	44	60	33 (-25%)	45 (-25%)
Energy "stand by"	16	22	12 (-25%)	16 (-25%)
"End of Life"	30	3	30	3
TCO and TECO	**765**	**293**	**840 (+10%)**	**303 (+3%)**

Table 6.1. General financial data of trucks, lorries and vans (EVO, 1999) (Kuipers, 1998).

All prices excl. VAT; diesel 0.56 Euro/litre	Truck+trailer net 24 tons	Lorry net 5 tons	Van net 5 m2
(1) Purchase price (Euro)	135,000	36,000	13,000
(2) Total distance in life time (km)	1,000,000	350,000	200,000
(3) Diesel fuel (litres/km)	0.33	0.21	0.13
(4) Max. distance one set tyres (km)	100,000	90,000	50,000
Eurovignet (Euro/annum)	1255		
Tax (Euro/annum)	910	750	500
Insurance (Euro/annum)	6850	2500	1000
Interest (Euro/annum)	2720	1000	300
(5) Subtotal yearly costs (Euro/annum)	11,735	4,250	1,800
(6) Total distance per year (km/annum)	140,000	70,000	50,000
(7) Max. pallets (1.00 × 1.25m) per trip	26	10	2
Costs per distance (Euro/km):			
Depreciation =(1)/(2) (Euro/km)	0.135	0.103	0.065
Diesel =(3)*0.56 (Euro/km)	0.185	0.118	0.073
Lube oil (Euro/km)	0.004	0.003	0.001
Maintenance (Euro/km)	0.07	0.03	0.01
Tyres (Euro/km)	0.047	0.02	0.01
Yearly costs =(5)/(6) (Euro/km)	0.084	0.06	0.036
Total (Euro/km)	**0.525**	**0.334**	**0.195**

Table 6.2. Eco-cost data of trucks, lorries and vans.

All values in Euro/km Note: all tyres in eco-costs of vehicle	Truck+trailer net 24 tons	Lorry net 5 tons	Van net 5 m2
Pollution prevention costs materials (Table 6.3, 6.6, 6.9)	0.032	0.023	0.023
Eco-costs of materials depletion (Table 6.4, 6.7, 6.10)	0.005	0.004	0.003
Eco-costs of assembling (Table 6.5, 6.8, 6.11)	0.016	0.014	0.008
Eco-costs of distribution (Table 6.5, 6.8, 6.11)	0.007	0.004	0.003
Eco-costs of end-of life (Table 6.5, 6.8, 6.11)	-	-	-
Sub total eco-costs of vehicle	**0.060**	**0.045**	**0.037**
Eco-costs of maintenance (EVR=0.2) ****)**	0.014	0.006	0.002
Eco-costs of diesel fuel (1.03 Euro/litre) ***)**	0.340	0.216	0.134
Sub total eco-costs of use	**0.354**	**0.222**	**0.136**
Total eco-costs (Euro/km)	**0.414**	**0.267**	**0.173**

*) see Section 3, including all (i.e. depletion and emissions)

**) "guestimate", derived from macro-economic data, methodology see Section 3

Table 6.3. Pollution prevention costs '99 for materials of a truck+trailer.

all data in kg	greenhouse	acidification	eutroph.	hv metals	carcin.	s. smog	w.smog
Truck:	kg CO2 equ	kg SO4 equ	kg PO4 eq	kg Pb equ	kg B(a)P equ	kg ethene eq	kg SPM equ
Steel, 6000kg	6263	30.43	1.861	0.003212	0.0035351	71.70884	27.49697
PVC, 500kg	1050	18.28	1.271	0.003	0	4.179	2.95
Glas, 50kg	37	0.22	0.016	0.002292	9.25E-06	0.03455	0
SBR [, 2000kg	2528	48.97	3.366	0	0	12.23304	5.6615
Aluminium,200kg	2460	25.55	0.565	4.30E-05	4.46E-07	0.79628	29.68666
Copper, 100kg	753	108.16	0.331	1.41E-05	9.48E-08	0.03350	106.3847
Machining,4500kg steel	249	1.60	0.073	0.001809	1.25E-04	0.05671	1.20175
Castwork, 1500 steel	2493	12.35	0.633	1.064076	0.0007485	3.61045	13.71558
Kopper (wire), 100kg	.154	0.47	0.031	0.000371	2.57E-05	0.34752	0.305106
Aluminium extrusion, 200kg	249	·1.60	0.073	0.001814	0.000125	0.05687	1.205174
total:	13965	203.59	5.194	1.07663	0.004569	82.04704	183.5121
Trailer:							
Steel, 4800kg	5011	24.34	1.488	0.002569	0.002828	57.36707	21.99757
Aluminium, 653kg	8031	83.43	1.845	0.00014	1.45671E-06	2.59986	96.92694
Wood, 306kg	89	0.67	0.086	2.29E-05	1.78E-07	0.50473	0.267025
SBR I, 2300kg	2907	56.32	3.871	0	0	14.06799	6.51073
Machining, 4800kg steel	265	1.70	0.078	0.001929	1.33E-04	0.06049	1.281866
total	13689	115.79	3.886	0.00466	0.002963	61.93897	121.1245
TOTAL Truck+ Trailer	32546	414.16	15.595	1.08129	0.007532	167.6569	315.5916

Multiplier (Euro/kg)	0.114	6.4	3.05	680	12.3	50/0.398	12.3
Poll.Prev.costs (Euro)	3710	2650	48	735	0	21062	3881
Total pollution prevention costs '99:			32086 (Euro)	or	0.032 (Euro/km)		

Weight of materials in the first column are derived from (Kuhndt, 1999), (Bos, 1998) and own calculations.
The classification/characterization results of the other columns derived from Simapro.
For calculation of poll. prev. costs and the multiplier in the bottom block, see Section 2.
Note: for summer smog ethene equivalent has been taken instead of VOC equivalent (factor 0.398)

Table 6.4. Eco-costs of materials depletion a truck+trailer.

	Weight	Raw material (Euro/kg)	Eco-costs of materials depletion (Euro)
Aluminium	300 + 653kg	1.40	1334
Copper	100kg	1.90	190
Steel	6000 + 4800kg	0.30	3240
PVC	500kg	0.60	300
Wood	306kg	1.00	306
Total Eco-costs of materials depletion:	5370 (Euro) or 0.005 (Euro/km)		

Weight of materials in the first column are derived from (Kuhndt, 1999), (Bos, 1998) and own
calculations. For calculation of eco-costs of materials depletion, see Section 3.

Table 6.5. Eco-costs of assembling, distribution and EoL of a truck+trailer.

	added value	EVR	eco-costs	eco-costs
assembling	80,000 Euro	0.2	16,000 Euro	0.016 (Euro/km).
distribution(dealer network)	45,000 Euro	0.15	7,000 Euro	0.007 (Euro/km)
End-of-life costs	<1,000 Euro	<1	<1,000 Euro	negligible

Table 6.6. Pollution prevention costs '99 for materials of a lorry.

all data in kg	greenhouse kg CO2 equ.	acidification kg SO4 equ.	eutroph. kg PO4 eq	hv. metals kg Pb equ	carcin kg B(a)P eq	s. smog kg ethene eq	w.smog kg SPM eq
steel, 2500kg	2609	12.6	0.77	0.001338	0.001473	29.87	11.45
PVC, 200kg	420	7.3	0.50	0.0012	0	1.67	1.18
glas, 30kg	22	0.1	0.01	0.001375	5.55E-06	0.02	0
SBR I, 500kg	632	12.2	0.84	0	0	3.05	1.41
Aluminium, 300kg	3690	38.3	0.84	6.45E-05	6.69E-07	1.19	44.52
Copper, 50kg	376	54.0	0.16	7.07E-06	4.74E-08	0.01	53.19
wood, 100kg	29	0.2	0.02	7.48E-06	5.81E-08	0.16	0.08
machining, 1750kg staal	96	0.6	0.02	0.000703	4.87E-05	0.02	0.46
Castwork, 750kg	1246	6.1	0.31	0.532038	0.000374	1.80	6.85
kopperwire, 50kg	77	0.2	0.01	0.000185	1.28E-05	0.17	0.15
Total:	9201	132.0	3.53	0.536918	0.001915	38.00	119.34

Multiplier (Euro/kg)	0.114	6.4	3.05	680	12.3	50/0.398	12.3
Poll.Prev.costs (Euro)	1049	845	10.7	365	0	4473	1467
Total pollution prevention costs '99:	**8209 (Euro)**	**or**	**0.023 (Euro/km)**				

Weight of materials in the first column are derived from (Kuhndt, 1999), (Bos, 1998) and own calculations.
The classification/characterization results of the other columns derived from Simapro.
For calculation of poll. prev. costs and the multiplier in the bottom block, see Section 2
Note: for summer smog ethene equivalent has been taken instead of VOCequivalent (factor 0.398)

Table 6.7. Eco-costs of materials depletion of a lorry.

	Mass	Eco-costs (Euro/kg)	Eco-costs of materials depletion (Euro)
Aluminium	300kg	1.40	420
Copper	50kg	1.90	95
Steel	2500kg	0.30	750
PVC	200kg	0.60	120
Wood	100kg	1.00	100
Total Eco-costs of materials depletion:	**1485 (Euro) or 0.004 (Euro/km)**		

Weight of materials in the first column are derived from (Kuhndt, 1999), (Bos, 1998) and own
calculations. For calculation of eco-costs of materials depletion, see Section 3

Table 6.8. Eco-costs of assembling, distribution and EoL of a lorry.

	added value	EVR	eco-costs	eco-costs
assembling	25,000 Euro	0.2	5,000 Euro	0.014 (Euro/km)
distribution(dealer network)	10,000 Euro	0.15	1,500 Euro	0.004 (Euro/km).
End-of-life costs	<600 Euro	<1	<600 Euro	negligible

Table 6.9. Pollution prevention costs '99 for materials of a van.

all data in kg	greenhouse kg CO₂ equ.	Acidification kg SO₄	eutroph. kg PO₄	hv. metals kg Pb	Carcin. kg B(a)P	s. smog kg ethene	w.smog kg SPM
Steel, 1550kg	1618	7.8	0.48	0.00083	0.00091324	18.52	7.10
PVC, 125kg	262	4.5	0.31	0.00075	0	1.04	0.73
Glas, 25kg	18	0.1	0.00	0.001146	4.62E-06	0.01	0
SBR I, 200kg	253	4.8	0.33	0	0	1.22	0.56
Aluminium, 70kg	861	8.9	0.19	1.51E-05	1.56E-07	0.27	10.39
Copper, 30kg	226	32.4	0.09	4.24E-06	2.84E-08	0.01	31.91
Machining, 1050kg	58	0.3	0.01	0.000422	2.92E-05	0.01	0.28
Castwork, 500kg	831	4.1	0.21	0.354692	0.000249514	1.20	4.57
Copperwire, 30kg	46	0.1	0.00	0.000111	7.70E-06	0.10	0.09
Aluminium extrusion, 70kg	87	0.5	0.02	0.000635	4.39144E-05	0.01	0.42
Totaal:	**4263**	**64.0**	**1.70**	**0.358605**	**0.00124837**	**22.44**	**56.08**

Multiplier (Euro/kg)	0.114	6.4	3.05	680	12.3	50/0.398	12.3
Poll.Prev.costs (Euro)	486	410	5.1	243	0	2819	690
Total pollution prevention costs '99: 4653 (Euro) or 0.023 (Euro/km)							

Weight of materials in the first column are derived from (Kuhndt, 1999), (Bos, 1998) and own calculations.
The classification/characterization results of the other columns derived from Simapro.
For calculation of poll. prev. costs and the multiplier in the bottom block, see Section 2.
Note: for summer smog ethene equivalent has been taken instead of VOC equivalent (factor 0.398)

Table 6.10. Eco-costs of materials depletion of a van.

	Mass	Eco-costs (Euro/kg)	Eco-costs of materials depletion (Euro)
Aluminium	70kg	1.40	98
Copper	30kg	1.90	57
Steel	1550kg	0.30	465
PVC	125kg	0.60	75
		Total Eco-costs of materials depletion:	**695 (Euro) or 0.003 (Euro/km)**

Weight of materials in the first column are derived from (Kuhndt, 1999), (Bos, 1998) and own
calculations. For calculation of eco-costs of materials depletion, see Section 3

Table 6.11. Eco-costs of assembling, distribution and EoL of a van.

	added value	EVR	eco-costs	eco-costs
assembling	8,000 Euro	0.2	1,600 Euro	0.008 (Euro/km)
distribution(dealer network)	4,000 Euro	0.15	600 Euro	0.004 (Euro/km).
End-of-life costs	<150 Euro	<1	<150 Euro	negligible

Table 6.12. Financial data of Forklift Trucks (Brantjes, 1999) (Caterpillar, 1999)

All prices excl. VAT; electicityl 0.094 Euro/kWh	Forklift Truck
(1) Purchase price (Euro)	21,000
(2) Total life time (years)	15
(3) Total life time (hours)	25,000
(4) Average operating hours per day	10
(5) Occupancy rate	70%
(6) Power cons. during oper. (kWh/hour)	51
(7) Battery life (hours)	6,250
(8) Tyre life (hours)	8,300
(9) Maintenance costs per annum (Euro)	1,050
Costs per hour (Euro):	
Depreciation $=(1)/(3)$ (Euro/hour)	0.84
Electrical power $=(6)*0.094$ (Euro/hour)	4.79
Maintenance (Euro/hour)	0.63
Total (Euro/hour)	**6.26**

Table 6.13. Eco-cost data of forklift trucks.

All values in Euro/hour Note: all tyres in eco-costs of vehicle	Forklift Truck
Pollution prevention costs materials (Table 6.14)	0.32
Eco-costs of materials depletion (Table 6.15)	0.06
Eco-costs of assembling (Table 6.16)	0.10
Eco-costs of distribution (Table 6.16)	0.04
Eco-costs of end-of life (Table 6.16)	-
Sub total eco-costs of the forklift truck	**0.52**
Eco-costs of maintenance (EVR=0.2) **)	0.12
Eco-costs of electrical power (0.118 Euro/kWh) *)	6.02
Sub total eco-costs of use	**6.14**
Total eco-costs (Euro/hour)	**6.66**

*) see (Vogtländer et al., 2000b), including all (i.e. depletion and emissions)

**) "guestimate", derived from macro-economic data, methodology see Section 3

Table 6.14. Pollution prevention costs '99 for materials of a forklift truck.

Including tyres and batteries during life time

all data in kg	greenhouse	acidification	eutroph.	hv. metals.	Carcin.	s. smog	w.smog
	kg CO2 equ.	kg SO4 eq.	kg PO4 eq	kg Pb equ.	kg B(a)P eq	kg ethene eq	kg SPM eq
steel, 2250kg	2348	11.4	0.697878	0.001204	0.001326	26.89	10.31
lead, 1200kg	2463	56.6	0.724112	0.000431	4.48E-06	0.43	49.56
Sulfuric acid, 2800kg	251	73.5	0.448669	0.004903	0.000822	0.24	0
SBR I, 90kg	113	2.2	0.151509	0	0	0.55	0.25
Copper, 50kg	376	54.0	0.165524	7.07E-06	4.74E-08	0.01	53.19
castwork, 1000kg	1662	8.2	0.422291	0.709384	0.000499	2.40	9.14
machining, 1250kg	69	0.4	0.020457	0.000502	3.48E-05	0.01	0.33
copperwire, 50kg	77	0.2	0.015651	0.000185	1.28E-05	0.17	0.15
total:	7363	206.8	2.646091	0.716618	0.002699	30.73	122.95

Multiplier (Euro/kg)	0.114	6.4	3.05	680	12.3	50/0.398	12.3
Poll.Prev.costs (Euro)	839	1323	8	487	0	3860	1512
Total pollution prevention costs '99: 8029 (Euro) or 0.32 (Euro/hour)							

Weight of materials in the first column are derived from own calculations (Brantjes, 1999).
The classification/characterization results of the other columns derived from Simapro.
For calculation of poll. prev. costs and the multiplier in the bottom block, see Section 2.
Note: for summer smog ethene equivalent has been taken instead of VOC equivalent (factor 0.398)

Table 6.15. Eco-costs of materials depletion of a forklift truck.

	Mass	Eco-costs (Euro/kg)	Eco-costs of materials depletion (Euro)
Steel	2250 kg	0.30	675
Copper	50 kg	1.90	95
Lead	1200 kg	0.55	660
Plastic	40 kg	0.60	24
Total Eco-costs of materials depletion: 1454(Euro) or 0.058 (Euro/hour)			

Weight of materials in the first column are derived from own calculations (Brantjes, 1999). For
calculation of eco-costs of materials depletion, see Section 3.

Table 6.16. Eco-costs of assembling, distribution and EoL of a van.

	added value	EVR	eco-costs	eco-costs
assembling	13,000 Euro	0.2	2,600 Euro	0.10 (Euro/km)
distribution(dealer network)	7,000 Euro	0.15	1,000 Euro	0.04 (Euro/km).
End-of-life costs	<500 Euro	<1	<500 Euro	negligible

Table 6. 17. Financial data of a warehouse.

All prices excl. VAT; electicity 0.094 Euro/kWh	Warehouse (unconditioned)	Warehouse (conditioned)
(1) Investment on building (Euro)	400,000	450,000
(2) Total life time (years)	25	25
(3) Nr of storage positions for pallets	920	920
(4) Maintenance (Euro/year)	7,050	17,800
(5) Energy consumption (kWh/year)	21,000	246,000
(6) Energy costs per year (Euro/year)	1974	23,500
(7) Interest (Euro/year)	12,000	13,500
(8) Insurance (Euro/year)	4,000	4,500
Costs per pallet per year (Euro):		
Depreciation =(1)/(2*3) (Euro/pallet.year)	17.4	19.6
Electricity =(6)/(3)*0.094 (Euro/pallet.year)	2.1	25.1
Maintenance (Euro/pallet.year)	7.7	19.3
Interest and insurance (Euro/pallet.year)	17.4	19.6
Total (Euro/pallet.year)	**44.6**	**83.6**

Table 6.18. Eco-cost data of a warehouse.

All values in Euro per pallet. Year	Warehouse (unconditioned)	Warehouse (conditioned)
Pollution prevention costs materials (Table 6.19)	6.8	7.6
Eco-costs of materials depletion (Table 6.20)	1.2	1.3
Eco-costs of manufacturing and construction (Table 6.21)	3.1	3.5
Eco-costs of end-of life	-	-
Sub total eco-costs of the warehouse	**11.1**	**12.4**
Eco-costs of maintenance (EVR=0.2) ****)**	1.5	3.9
Eco-costs of electrical power (0.118 Euro/kWh) ***)**	2.7	31.5
Sub total eco-costs of use	**4.2**	**35.4**
Total eco-costs (Euro/pallet.year)	**15.3**	**47.8**

*) see Section 3, including all (i.e. depletion and emissions)
**) "guestimate", derived from macro-economic data, methodology see Section 3

Table 6.19. Pollution prevention costs '99 for a warehouse of 920 pallets.

all data in kg	greenhouse kg CO2 equ	acidification kg SO4 equ	eutroph. kg PO4 eq	hv. metals kg Pb equ	carcin kg B(a)P eq	s. smog kg ethene eq	w.smog kg SPM eq
Concrete, reinforced, 551200kg	59629	484.6	51.0744	0.4563	0.015109	21.37	6489.65
Fe360, 51000kg	58271	708.1	63.6528	1.0514	0.034922	31.61	427.33
steel sheet, 22000kg	38585	214.4	12.0904	0.1228	0.020775	266.56	175.94
PS, 40kg	164	0.2	0.03811	0	2.16E-07	0.2013	0.15
PS foaming, 40kg	222	3.3	0.07492	0.0043	0.000722	0.82	0
steel transforming, 22000kg	1449	9.6	0.44312	0.0108	0.000753	0.34	7.23
steel transforming, 51000kg	3475	22.3	1.02724	0.0252	0.001745	0.79	16.76
Total:	161798	1442.9	128.40	1.6711	0.074026	321.71	7117.08

Multiplier (Euro/kg)	0.114	6.4	3.05	680	12.3	50/0.398	12.3
Poll.Prev.costs (Euro)	18445	9235	392	1136	1	40415	87540

Total pollution prevention costs '99: 157164 (Euro) or 6.8 (Euro/pallet per year)

Weight of materials in the first column are derived from own calculations (Brantjes, 1999).
The classification/characterization results of the other columns derived from Simapro.
For calculation of poll. prev. costs and the multiplier in the bottom block, see Section 2.
Note: for summer smog ethene equivalent has been taken instead of VOC equivalent (factor 0.398)

Table 6.20. Eco-costs of materials depletion of a warehouse.

Warehouse (920 pallets)	Weight (kg)	Eco-costs (Euro/kg)	Eco-costs of materials depletion (Euro)
Steel for structure	51000	0.30	15300
PS-foam	40	0.60	24
Steel in concrete	22000	0.30	6600
Steel for cladding	22000	0.30	6600
Total Eco-costs of materials depletion:	28524 (Euro) or 1.2 (Euro/pallet per year)		

Weight of materials in the first column are derived from own calculations (Brantjes, 1999). For calculation of eco-costs of materials depletion, see Section 3.

Table 6.21. Eco-costs of manufacturing and construction of a warehouse.

	added value	EVR	eco-costs	eco-costs
unconditioned	360,000 Euro	0.2	72,000 Euro	3.1 (Euro/pallet per year).
Conditioned	400,000 Euro	0.2	80,000 Euro	3.5 (Euro/pallet per year).
End-of-life costs	negligible	<1	negligible	negligible

Note: the EVR of this unconditioned warehouse is:
EVR = (132834 + 28524 + 72000) / (400000) = 0.58

Table 6.22. General data on transport packaging.

	Re-usable plastic crates	Solid board boxes ("trays")
Content per pallet	2279 (litres)	2467 litres
Costs of tra. packaging per pallet	11.00 (Euro)	49.50 (Euro)
Eco-costs of tra. packaging per pallet	6.05 (Euro)	7.26 (Euro)

Table 7.1: The values for $S_{1\ ha}$ and b according to (Köllner, 2000), S rounded off in units of 5, and predictions of data for S and $S_{ref.}$ of other area sizes by equation [7.3a] and [7.3b].

CORINE nr.[*]	Land type	$S_{.1\ ha}$	b	predicted data according to equation [7.3]			
				$S_{2\ ha}$	$S_{5\ ha}$	$S_{10\ ha}$	$S_{20\ ha}$
1.1.1	Continuous urban	10	?	?	?	?	?
1.1.2	Discontinuous urban	55	0.38	72	101	132	172
1.1.3	Urban fallow	90	0.18	102	120	136	154
1.2.1	Industrial area	80	0.22	93	114	133	155
1.2.2.2	Rail area	80	0.22	93	114	133	155
1.2.5	Industrial fallow	105	0.20	121	145	166	191
1.3.4	Mining fallow	85	0.28	103	133	162	197
1.4.1	Green urban	80	0.34	101	138	175	222
1.5	Build-up land	0	0.00	0	0	0	0
2.2.1.1	Conventional arable	10	0.45	14	21	28	39
2.2.1.2	Integrated arable	10	0.50	14	22	32	45
2.2.1.3	Organic arable	25	0.45	34	52	70	96
2.3.1.1	Intensive meadow	15	0.41	20	29	39	53
2.3.1.2	Less intensive meadow	40	0.38	52	74	96	125
2.3.1.3	Organic meadow	45	0.40	59	86	113	149
3.1.1	Broad-leafed forest [**]	245	0.13	268	302	330	362
-	Swiss low lands	270	0.13	295	333	364	399
-	$S_{ref.}(S_{ref.}=250$ for 1 km^2)	137.5	0.13	150	169	150	203

[*] Numbers according to (CORINE, 2000) Note: ? means that extrapolation is not possible.
[**] Köllner gives $b=0.36$, but this value results in unrealistic data; $b=0.13$ (Swiss low lands) is proposed

Table 7.2: The values for $\Delta SRI / SRI_{original}$ for $b = 0.2$ and $b = 0.4$ according to equation [A.7.7]

β	$\Delta SRI / SRI_{original}$ for b = 0.2	$\Delta SRI / SRI_{original}$ for b = 0.4
0.0	0	0
0.1	0.06	0.10
0.2	0.09	0.16
0.3	0.11	0.21
0.4	0.13	0.23
0.5	0.13	0.24
0.6	0.13	0.23
0.7	0.11	0.21
0.8	0.09	0.16
0.9	0.06	0.10
1.0	0	0

Table 7.3: The eco-costs of 'scenic beauty' for 12 Dutch provinces (equation [7.12] and [7.13]).

	Land (km^2)	P (people/km²)	$\frac{P}{P_{norm}}$	Build-up (km^2)	Build-up P (people/km²)	PSR	$\frac{PSR}{PSR_{norm}}$	Eco-cost $(Euro/m^2)$
Groningen	2340	239	0.20	156	3590	1.07	0.88	81
Friesland	3357	185	0.16	150	4141	1.05	0.86	61
Drente	2650	176	0.15	146	3199	1.06	0.87	59
Overijssel	3336	321	0.27	226	4736	1.07	0.89	108
Flevoland	1421	216	0.18	59	5195	1.04	0.86	71
Gelderland	4989	382	0.32	422	4518	1.09	0.90	132
Utrecht	1358	809	0.69	201	5466	1.17	0.97	299
Noord-Holland	2657	942	0.80	418	5989	1.19	0.98	352
Zuid-Holland	2867	1179	1.00	501	6744	1.21	1.00	450
Zeeland	1789	207	0.18	96	3860	1.06	0.87	69
Noord-Brabant	4930	474	0.40	549	4258	1.13	0.93	168
Limburg	2163	527	0.45	282	4040	1.15	0.95	191

Table 7.4: The species richness S* (species number of vascular plants per 10,000 km²) and the estimated eco-costs of species richness (Euro/m²) for 94 countries (equation [A.7.17]). Derived from (Barthlott, 1998).

Country	S*	eco-costs (Euro/m²)	Country	S*	eco-costs (Euro/m²)	Country	S*	eco-costs (Euro/m²)
africa			**north&centr america**			**asia (cont.)**		
algeria	1500	4.8	canada	1000	3.2	mongolia	1000	3.2
angola	1500	4.8	costa rica	5000	16	oman	100	0.32
botswana	500	1.6	cuba	3000	9.6	pakistan	500	1.6
cameroon	5000	16	dominican rp.	2500	8	philippines	4000	12.8
congo	4000	12.8	greenland	100	0.32	saudi arabia	100	0.32
egypt	200	0.6	haiti	2500	8	sri lanca	2000	6.4
ethiopia	1500	4.8	honduras	3000	9.6	thailand	3000	9.6
gabon	4000	12.8	jamaica	2500	8	turkey	1500	4.8
ghana	1500	4.8	mexico	3000	9.6	vietnam	4000	12.8
guinea	1500	4.8	panama	5000	16	**europe**		
kenya	1500	4.8	united states	1500	4.8	albania	2000	6.4
liberia	2000	6.4	**south amer.**			austria	1500	4.8
libya	200	0.6	argentina	1000	3.2	bulgaria	2000	6.4
madagascar	3000	9.6	bolivia	5000	16	czechoslov.	1500	4.8
mauretania	100	0.32	brazil	2000	6.4	finland	500	1.6
morocco	1500	4.8	chile	1500	4.8	france	1500	4.8
mozambique	1500	4.8	colombia	4000	12.8	germany	1250	4
nambia	500	1.6	french guiana	3000	9.6	greece	2000	6.4
niger	100	0.32	guyana	3000	9.6	ireland	1000	3.2
nigeria	2000	6.4	peru	5000	16	italy	2000	6.4
sierra leone	2000	6.4	suriname	3000	9.6	netherlands	1250	4
south africa	3000	9.6	venezuela	3000	9.6	norway	500	1.6
sudan	100	0.32	**asia**			poland	1000	3.2
tanzania	3000	9.6	china	1500	4.8	romania	1500	4.8
tunesia	1500	4.8	cyprus	2000	6.4	spain	1500	4.8
uganda	2000	6.4	india	1500	4.8	sweden	500	1.6
zaire	2000	6.4	indonesia	4000	12.8	UK	1000	3.2
zambia	1500	4.8	iran	1000	3.2	yugoslavia	1500	4.8
zimbabwe	1500	4.8	iraq	200	0.64	**USSR**	1000	3.2
			japan	1500	4.8	**oceania**		
			north korea	1500	4.8	australia	1000	3.2
			south korea	1500	4.8	nw caledonia	3000	9.6
			lao	3000	9.6	new zealand	1000	3.2
			malaysia	3000	9.6	new guinea	4000	12.8
						solomon isls	3000	9.6

Table 8.1 Indicative data on the costs of repair of an induction plate cooker.

	Chance of repair in 10 years	Costs of service (a)	Costs of parts (b)	Total costs of Repair (a) + (b)	Extra costs of induction cooker
"Conventional"	60%	65 Euro	75 Euro	140 Euro	-
"The first time right"	60%	50 Euro	75 Euro	125 Euro	4.5- 9 Euro
"Easy to repair by the client"	60%	-	80 Euro	80 Euro	35 Euro
"Designed for less maintenance"	24%	50 Euro	75 Euro	125 Euro	180 Euro

Table 8.2. Is sustainability part of the choice and should the government stimulate internet?

	Business group	Government group
total number of participants	8	11
Question 1:		
- sustainability was part of the motivation	1	4
- sustainability was *not* part of the motivation	7	6
Question 2:		
- government should stimulate internet solution	4	4
- government should *not* stimulate internet solution	1	3
- don't know	3	4

Table 8.3. "Overall" test results.

		Consumer group			Business group			Govern. group		
		yes	no	?	yes	no	?	yes	no	?
1	Did the participants take the new model for the third ranking?	8	1		7	1		3	8	
2	The answer on: "I accept the data of the eco-cost/value model as a reliable source of information"	5	2	(2)	4	1	(3)	0	10	?
3	The answer on: "I can well understand the data from the eco-costs/value model"	4	4	(1)	3	4	(1)	4	6	(1)

Table 8.4. The paradigms of the three groups (questionnaire at the beginning of the sessions).
(the bold numbers mark that the opinion of the majority of a group is different from other groups)

	Question	Consumer group			Business group			Governm. group		
		yes	no	?	yes	no	?	yes	no	?
1	A consumer will try to buy the best possible value for the lowest possible price.	8	1		8	0		11	0	
2	For most consumers price is more important than the environmental aspects of a product	6	3		7	1		11	0	
3	A negative image on environmental issues can cause serious damage in business	9	0		5	2	(1)	9	0	(2)
4	Businesses can achieve a competitive edge by pro-active marketing of sustainable products	9	0		7	1		10	0	(1)
5	The Government has the responsibility for safeguarding a sustainable future	9	0		6	2		9	1	(1)
6	Sustainability can only be achieved by a combined effort of the 3 stakeholders	9	0		8	0		10	0	(1)
7	The Government must make regulations in order to control environmental pollution by industry	7	1	(1)	8	0		9	0	(2)
8	The Governmental Policy on environmental issues must be stable to enable long term strategies in the industry	9	0		8	0		9	0	(2)
9	The citizens determine via politics how much money we are prepared to spend on environmental issues	5	3	(1)	**1**	7		7	2	(2)
10	The Government must limit the amount of money spent on environmental issues	1	8		**5**	2	(1)	**2**	7	(2)
11	The industry will only limit their environmental burden when that is required by the government	1	7	(1)	2	6		1	10	
12	The industry will only limit their environmental burden when that is required in the market	6	3		3	5		3	7	(1)
13	Governmental regulations that place our national industry in an unfavourable competitive position should not be allowed	**4**	5		**8**	0		**2**	8	(1)

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Web site WBCSD	www.wbcsd.ch/eurint/eeei.htm

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Samenvatting

Het model van de Eco-kosten / Waarde Ratio

De Ecokosten / Waarde Ratio, EWR

De basisgedachte van het model van de EWR (Ecokosten / Waarde Ratio) is de link tussen de 'waardeketen' (Porter, 1985) en de 'productketen' uit de milieukunde. In de waardeketen worden de toegevoegde waarde (in het economisch verkeer) en de kosten bepaald voor iedere stap in de productieketen, "van zand tot klant". Op soortgelijke wijze kan men de milieubelasting bepalen voor iedere stap in de productieketen, en deze milieubelasting uitdrukken in geld, de zogenaamde ecokosten. Zie Figuur A.

| **Waarde:** | waarde | + | Δwaarde | + | Δwaarde | + | Δwaarde | + | Δwaarde | + | Δwaarde | **= Totale waarde** |

| **Kosten:** | kosten | + | kosten | + | kosten | + | kosten | + | kosten | + | kosten | **= Totale kosten** |
| **Eco-kosten:** | eco-kosten | + | eco-kosten | + | eco-kosten | + | eco-kosten | + | eco-kosten | + | eco-kosten | **= Totale Eco-kosten** |
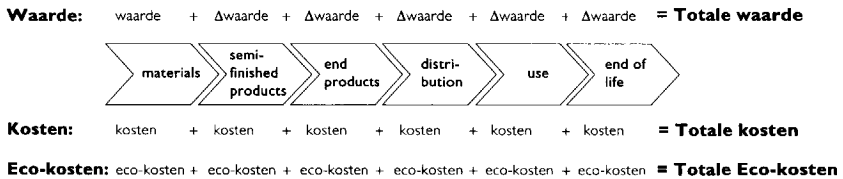
Fig. A: De basisgedachte van de "EWR keten": een integrale, gecombineerde, benadering van de keten, economisch zowel als milieukundig.

De ecokosten zijn 'virtueel': deze kosten worden bepaald op basis van de te nemen maatregelen om een product te maken (en te herverwerken) *"in line with earth's estimated carrying capacity"*[73]. Deze kosten zijn geschat op basis van de technische maatregelen die nodig zijn om milieuvervuiling en uitputting van grondstoffen tegen te

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[73] De World Business Council for Sustainable Development (www.wbcsd.ch/eurint/eeei.htm) heeft in 1995 de rol van de industrie beschreven door het begrip eco-efficiency te definiëren:
"the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity, through the life cycle, to a level at least in line with earth's carrying capacity."

gaan, tot het niveau dat nodig is voor een duurzame samenleving. Ecokosten zijn dus gebaseerd op de kosten van de benodigde *preventiemaatregelen* (de zogenaamde marginale preventiekosten). Omdat onze samenleving nog verre van duurzaam is, zijn de ecokosten 'virtueel': zij zijn ingeschat op basis van een 'what if' berekening. De ecokosten staan naast de gewone, private, kosten. Zij zijn op dit moment nog niet geïntegreerd in de lopende kosten van de productieketen (de lopende 'Life Cycle Costs'). De verhouding van de ecokosten en de waarde (in het economisch verkeer), de zogenaamde Ecokosten / Waarde Ratio, EWR, wordt voor iedere stap in de waardeketen gedefinieerd als:

$$EVR = \frac{ecokosten}{waarde}$$

Figuur B geeft de opbouw van de ecokosten, de kosten en de waarde[74] binnen de productieketen.
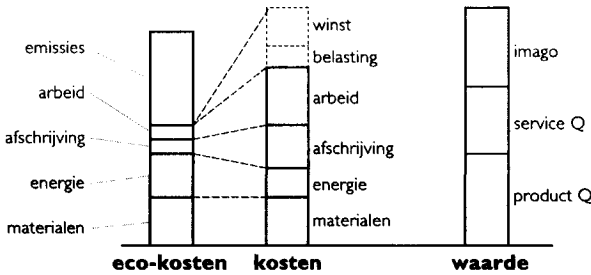
Fig. B: De opbouw van de 'virtuele ecokosten', de kosten en de waarde van een product.

De ecokosten worden opgebouwd uit 3 'directe' en 2 'indirecte' componenten:
✓ 'virtual pollution prevention costs'; dit zijn de kosten die nodig zijn om de *emissies* van de productieprocessen en het gebruik terug te dringen tot een duurzaam niveau
✓ ecokosten van *energie*; dit zijn de kosten van duurzame energie
✓ ecokosten van *materiaaluitputting*; dit wordt in het model gedefinieerd als (kosten van ruwe grondstoffen) $* (1-\alpha)$, waarbij α de fractie is van het recycled materiaal
✓ ecokosten van *afschrijving*; dit zijn de ecokosten die gerelateerd zijn aan het gebruik van productiemiddelen zoals gebouwen, machines, etc.
✓ ecokosten van *arbeid*; dit zijn de ecokosten die gerelateerd zijn aan arbeid, zoals de ecokosten van woon-werk verkeer, het gebruik van kantoren (het gebouw, de verwarming , verlichting, beeldschermen), het gebruik van papier en andere kantoorbenodigdheden, etc.

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[74] Binnen de productieketen is de waarde gelijk aan de prijs in de markt. Vanuit het oogpunt van de consument is de waarde gelijk aan de 'fair price' (Gale, 1994).

Opmerking: Binnen de productieketen is de waarde voor de verkoper gelijk aan de kosten voor de koper.

Wanneer de gedetailleerde kostenstructuur van het product bekend is, kan men de ecokosten gemakkelijk uitrekenen door ieder kostenelement te vermenigvuldigen met de specifieke Ecokosten / Waarde Ratio, de EWR. Deze specifieke EWRs worden berekend met behulp van de standaard LCA methodologie. Voor materialen, ener-gie en industriële processen zijn tabellen gemaakt met ecokosten en EWR waarden.

Eco-efficiency is in het EWR model gedefinieerd als:

$$eco\text{-}efficiency = \frac{(waarde - ecokosten)}{(waarde)} \text{ , of, } eco\text{-}efficiency = 1 - EVR$$

Merk op dat eco-efficiency de volgende waarde heeft:
- negatief wanneer de ecokosten hoger zijn dan de waarde, ofwel wanneer EVR > 1
- 0% wanneer de ecokosten gelijk zijn aan de waarde, ofwel wanneer EVR = 1
- 100% wanneer de ecokosten nul zijn, ofwel wanneer EVR = 0.

(Zie Hoofdstuk 3)

De 'pollution prevention costs'

De pollution prevention costs worden berekend in vier stappen:
1. LCA studie volgens de huidige standaards (ISO 14041)
2. Classificatie van de emissies voor 7 categorieën (klassen) van vervuiling
3. Karakterisatie volgens de karakterisatie systemen (de vermenigvuldigingsfactoren) die o.a. gebruikt zijn bij de Eco-indicator '95, en resulteren in 'kilogram-equivalent' voor de categorieën van vervuiling
4. Vermenigvuldiging van de kilogram-equivalenten uit stap 3 met de 'preventiekosten voor de duurzaamheidsnorm', d.w.z. de marginale kosten per kilogram die nodig zijn om de vervuiling terug te brengen tot een duurzaam niveau (*"in line with earth's carrying capacity"*).

De volgende 'preventiekosten voor de duurzaamheidsnorm' worden gehanteerd voor Nederland (en Europa):
- preventie van verzuring: 6.40 Euro/kg   (SO_x equivalent)
- preventie van vermesting: 3.05 Euro/kg   (fosfaat equivalent)
- preventie van zware metalen: 680 Euro/kg   (berekening gebaseerd op Zn)
- preventie van carciogenen: 12.3 Euro/kg   (PAH equivalent)
- preventie van zomer smog: 50.0 Euro/kg   (berekening gebaseerd op VOC eq.)
- preventie van winter smog: 12.3 Euro/kg   (berekening gebaseerd op fijne stofdeeltjes)
- preventie van broeikaseffect: 0.114 Euro/kg (CO_2 equivalent).

Deze 'preventiekosten voor de duurzaamheidsnorm' zijn gebaseerd op de zoge-naamde 'marginale preventie kosten' van emissie. De manier waarop deze marginale

preventiekosten worden bepaald, is weergegeven in Figuur C. Voor ieder type van emissie worden de kosten en de effecten van de verscheidene preventimaatregelen berekend en opgeteld (een 'what if' berekening). De duurzaamheidsnorm wordt op een bepaald punt op de kromme bereikt. De marginale preventie kosten worden nu gedefinieerd door de helling van lijn b: de kosten per kilogram emissiereductie van de laatste preventiemaatregel.

De duurzaamheidsnorm is gebaseerd op het Verwaarloosbaar Risico niveau voor de concentraties (in water en in lucht) en de bijbehorende relatie tussen concentratie en emissie (bepaald met een zogenaamde 'fate analyses').
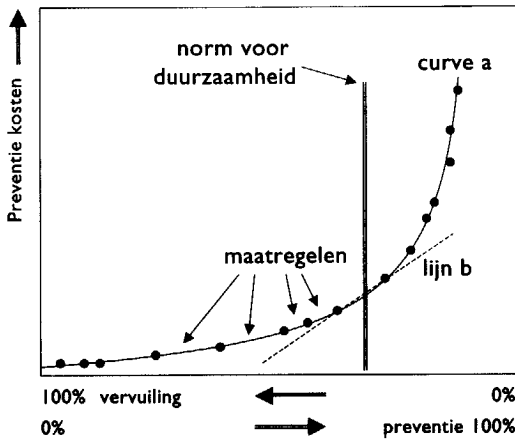
Fig. C: De methode om de marginale preventie kosten te berekenen van preventiemaatregelen voor emissie in een bepaalde regio.

(Zie Hoofdstuk 2)

De 'End of Life' fase

'End of Life' systemen zijn zeer complex. Voor samengestelde producten, zoals gebouwen, zijn vele mogelijkheden om het totaalsysteem meer duurzaam te maken.(van materiaalhergebruik tot verlenging van de levensduur).

In Figuur D zijn de belangrijkste vormen weergegeven van 'End of Life' systemen en vormen van materiaalhergebruik. De Figuur is ontwikkeld om de diverse alternatieven van complexe systemen te beschrijven en te analyseren voor consumenten pro-ducten, gebouwen, fabrieken, bruggen, etc.

De nummers in Figuur 5 verwijzen naar de "Delft Order of Preferences", een lijst van de 10 systemen voor de 'End of Life' fase, te gebruiken bij een systematische analyse van ontwerpalternatieven:
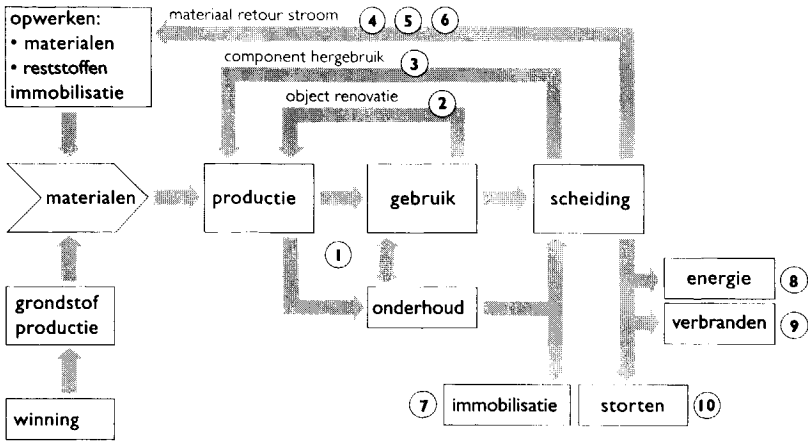
Fig. D: De materiaalstromen in de 'Life Cycle'.

1. Verlenging van de levensduur
2. Object renovatie
3. Hergebruik van componenten
4. Hergebruik van materialen
5. Nuttige toepassing van afval (compost, granulaat van steen en beton, slag, etc.)
6. Immobilisatie met nuttige toepassing
7. Immobilisatie zonder nuttige toepassing
8. Verbranding met energieopwekking
9. Verbranding zonder energieopwekking
10. Storten.

Het is van belang dat men zich realiseert dat er voor grote modulaire objecten (zoals gebouwen) niet "één systeem voor de End of Life fase" bestaat. In de praktijk zal het altijd een combinatie van de verschillende systemen zijn die het optimale resultaat biedt.

Het EWR model kent twee basis regels voor allocatie (zie Figuur D):
- De kosten en de ecokosten van alle activiteiten 'b' worden toebedeeld aan de End of Life fase van het (oude) product
- De kosten en de ecokosten van alle activiteiten 'b' worden toebedeeld aan het te gebruiken materiaal voor het nieuwe product (worden dus toebedeeld aan het begin van de productketen).

De 'bonus' voor hergebruik van materialen komt in het EWR model tot uiting aan het begin in de keten. In tegenstelling tot gerecyclede materialen, hebben materialen uit ertsen immers zowel hoge ecokosten van materiaaluitputting als hoge 'pollution prevention costs' vanwege winning en zuivering.

(Zie Hoofdstuk 4)

De EWR als een indicator voor de ontkoppeling van economie en ecologie

Het productontwerp voor de toekomst wordt gekenmerkt door een combinatie van een hoge verhouding van waarde/kosten, zowel als een hoge eco-efficiency.
De belangrijke praktische betekenis van het EWR model is dat het de ontkoppeling van economie en ecologie inzichtelijk maakt.

Voor ontwerpers is het EW Wiel ontwikkeld, dat de sterkte en zwakte van een ontwerp bloot legt, zowel met het oog op de waarde als met het oog op de ecokosten. Zie Figuur E. Een duurzaam ontwerp wordt gekarakteriseerd door een hoge score op het gebied van de waarde en een lage score op het gebied van de ecokosten.
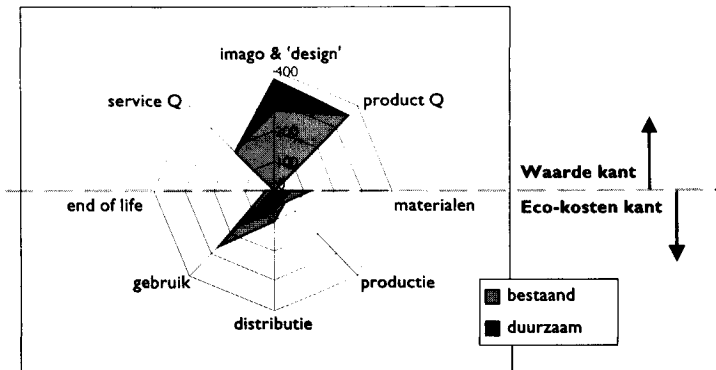
Fig. E: Het Ecokosten & Waarde Wiel (EW Wiel), met waarde en ecokosten in Euro.

Een ander krachtig instrument om een product op waarde en ecokosten te analyseren, is de grafiek waarin de ecokosten afgezet zijn tegen de waarde in de productie en distributie keten. De waarde en de ecokosten stijgen beide in de productieketen vanaf de grondstoffen tot het moment van verkoop. Dit wordt weergegeven in het voorbeeld van Figuur F: de productie en distributieketen van een 28" televisie.
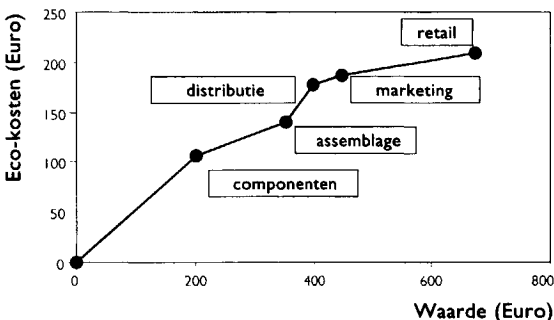
Fig. F: De waarde en de ecokosten, cumulatief weergegeven over de productie- en distributieketen
(gegevens van een 28" televisie).

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De EWR is eveneens een goede indicator van de duurzaamheid van het uitgavepatroon van consumenten. Het zogenaamde 'rebound effect' is gevisualiseerd in Figuur G. Uit deze figuur valt af te lezen dat 'besparingen' niet altijd even gunstig uitpakken voor het milieu. Wanneer ecokosten verminderd worden door besparingen, zal de consument eveneens geld overhouden en voor dit geld andere zaken van waarde kopen. In het voorbeeld van de besparing op product 1 van Figuur G is het netto resultaat positief, omdat het bespaarde geld besteed wordt aan product 2 en product 2 een lagere EWR heeft. Wanneer echter bespaard zou worden op product 2, en het bespaarde geld zou uitgegeven worden aan product 1, dan is het resultaat negatief, omdat het bespaarde geld uitgegeven wordt aan een product met een hogere EWR. De conclusie is dat 'besparingen' alleen positief uitpakken voor het milieu wanneer deze besparingen bereikt worden in product sectoren met een hoge EWR (en de bestedingen hiervan terecht komen in sectoren met een lage EWR).

Een specifiek voorbeeld van het rebound effect is de winst voor ons milieu vanwege de steeds zuiniger wordende lampen. Wanneer consumenten de bespaarde stroom gebruiken voor meer licht (bijvoorbeeld in de tuin) of voor meer elektriciteit voor andere apparatuur, is het uiteindelijke effect voor het milieu teniet gedaan.
In zijn algemeenheid kan men echter stellen dat besparingen in energie een overwegend positief effect op ons milieu zullen hebben, omdat de EWR van energie relatief hoog is (1.2 – 1.8) in vergelijking met andere producten die men kan kopen..
Besparingen op luxe goederen (in het algemeen met een lage EWR vanwege de hoge arbeidintensiviteit: 0.2 – 0.4), zullen in zijn algemeenheid minder gunstig zijn voor het milieu, omdat de rebound dikwijls in een energie-intensieve sector zal plaats vinden (bijv. in de vorm van reizen).
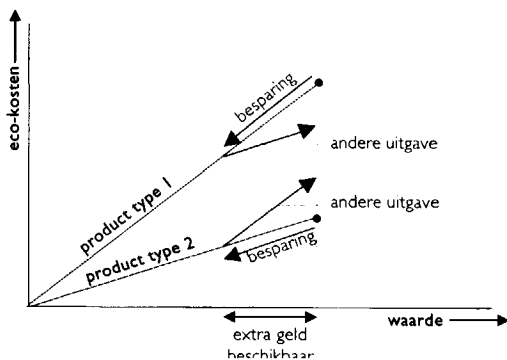
Fig. G: Het 'rebound effect' van bestedingen van consumenten.

(Zie Hoofdstuk 5)

Case: de transport functie

Om de kracht te illustreren van het EWR model in gevallen waarbij service een dominerende rol speelt, is een transportketen geanalyseerd: vervoer van groente van een kas in het Westland tot op het schap in een winkel in Frankfort. Deze keten is geanalyseerd voor twee typen van transportsystemen: een systeem met plastic kratten (retour systeem) en een 'one way' systeem van dozen van massief karton. Zie Figuur H.
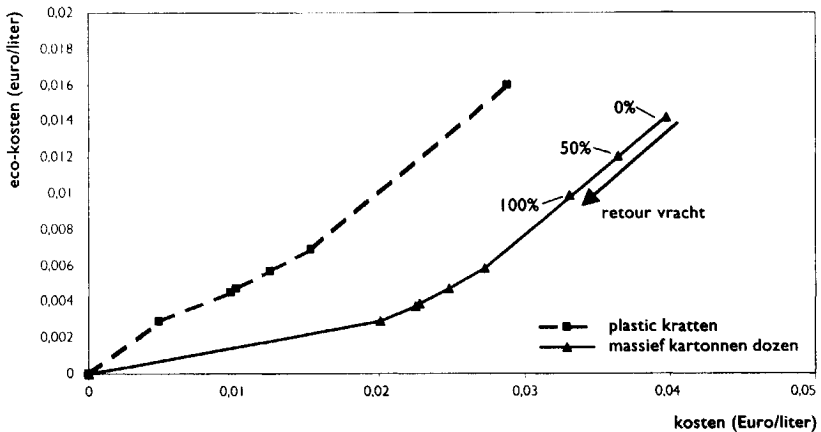
Fig. H:. De kosten en de ecokosten per liter netto transport volume voor de totale keten (over een afstand van 500 km) als functie van het percentage retour vracht.

Wanneer men een transportsysteem ontwerpt is een integrale LCA aanpak van de totale keten (cyclus) nodig om de ecokosten te minimaliseren. Dit vanwege de sterke interactie tussen de verschillende systeemcomponenten: het verpakkingssysteem, het transportsysteem en het systeem voor opslag. Efficiënt gebruik van volume (in de vrachtwagen, de transport verpakking en de opslag) speelt een zeer grote rol, evenals het hergebruik van de verpakking zelf. De ecokosten van het systeem met massief kartonnen dozen bleken het laagst is alle gevallen (ook voor de kortere afstanden), vooral wanneer de vrachtwagen op de retour trip gebruikt kan worden voor andere vracht. De EWR (en dus de eco-efficiency) van het systeem met massief kartonnen dozen bleek in alle gevallen eveneens beter. Dus is er vanuit milieu oogpunt geen enkele reden om retour kratten te prefereren, hetgeen een opmerkelijke conclusie is in het licht van de discussies die in Nederland begin jaren negentig gevoerd werden: 'milieuvriendelijk' gaat hier niet hand in hand met 'geschikt voor hergebruik', omdat het energiegebruik nogal dominant blijkt te zijn in de berekeningen van dit soort transportsystemen.

(Zie Hoofdstuk 6)

De ecokosten van landconversie

Ofschoon in dit proefschrift beargumenteerd is dat landgebruik niet goed geïntegreerd kan worden in de LCA van industriële massa producten, is er toch een karakterisatie systeem ontwikkeld voor conversie van land. Dit systeem kan gebruikt worden bij:
- LCAs van specifieke producten zoals gebouwen, wegen, e.d.
- Vraagstukken rond de ruimtelijke ordening, om het beste alternatief te kunnen selecteren en om maatregelen voor compensatie te kunnen vaststellen (bijv. in MER studies).

Het karakterisatiesysteem voor de ecokosten van landconversie is samengevat in Figuur I. In het rekenschema van Figuur I it te zien dat er twee 'category indicators' gebruikt kunnen worden voor de 'endpoint category' 'habitat voor planten': of SRI (voor soortenrijkdom) or ERI (voor zeldzame ecosystemen). Zowel SRI als ERI worden uitgedrukt in 'equivalent m^2 natuur'. Voor ERI is er een drempelwaarde bepaald: voor ERI/A groter is dan 1, zou conversie moeten worden verboden (A is hier de oppervlakte van het te converteren land).

Voor de endpoint category 'H$_2$O cyclus' is een indicator ontwikkeld voor de specifieke situatie van een polder. Voor andere situaties zou op basis hiervan de category indicator verder ontwikkeld kunnen worden (voor de conversie van groen naar bebouwd). De ecokosten van de 'H$_2$O cyclus' (en ook van 'voeding en biomassa') lijken in Nederland echter verwaarloosbaar in vergelijking met de ecokosten van landschapschoon ('scenic beauty').
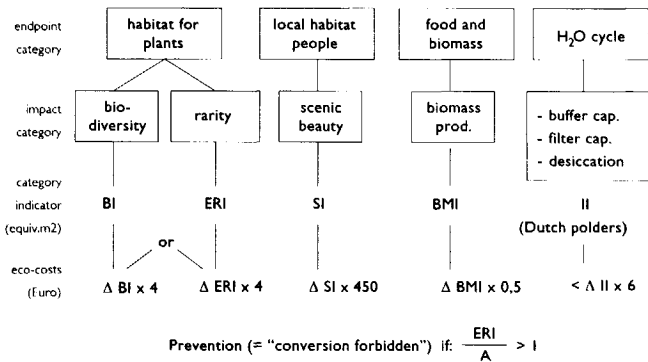
Fig. I: Karakterisatiesysteem voor landconversie, en de corresponderende ecokosten.

In berekeningen van ecokosten van landconversie lijken twee aspecten te overheersen:
a. de botanische waarde van natuur, in situaties waar een groene ruimte geconverteerd wordt naar een groene ruimte van een ander type
b. het landschapsschoon, in situaties waar groene ruimte in dichtbevolkte streken wordt geconverteerd naar bebouwd oppervlak.

De berekeningen van de ecokosten kunnen gebruikt worden om compensatiemaatregelen te bepalen in geval van vraagstukken rond ruimtelijke ordening. Een dergelijke compensatie moet bij voorkeur plaatshebben binnen iedere endpoint category afzonderlijk (d.w.z negatieve effecten op de H_2O kringloop moeten gecompenseerd worden met positieve maatregelen ten behoeve van diezelfde kringloop, en niet in een van de andere endpoint categories.

(Zie Hoofdstuk 7)

Communiceren met behulp van de ecokosten en de EWR

Een experiment is uitgevoerd om te testen of het EWR model al dan niet een goed inzicht geeft in de eco-efficiency van een product-dienst combinatie. Aan 3 separate groepen van 8-11 mensen is gevraagd om vier alternatieve oplossingen voor een product-service systeem te rangschikken naar duurzaamheid. Het betrof de after sales service en de onderhoudsservice van een inductie kookplaat.
De 3 groepen waren respectievelijk:
- consumenten (waaronder vertegenwoordigers van consumentenorganisaties)
- mensen uit het bedrijfsleven, in dit geval medewerkers van het productiebedrijf van de kookplaten
- vertegenwoordigers van de overheid (ambtenaren van EZ, VROM en van de provincies, plus consultants op het gebied van milieubeleid), allen deskundig op milieugebied.

De vraag werd gesteld om de getoonde oplossingen te rangschikken op volgorde van 'beste duurzaamheid', en tevens de rangorde aan te geven in termen van de 'algemene voorkeur bij aankoop'. Men moest verder aangeven op welke gronden men de keuzes gemaakt had. Ook werd gedurende de sessies steeds gevraagd of, en zoja welke, informatie gemist werd om, naar het gevoel van de deelnemers zelf, de juiste keuze van rangorde te kunnen maken.
Aan het eind van de sessies werd gevraagd of men het gevoel had gekregen dat de ecokosten en de EWR goede criteria waren om de beslissingen op te kunnen baseren

Uit de experimenten kan men de volgende conclusies trekken:
- Het concept Ecokosten werd door de meerderheid van de niet-experts geaccepteerd als maat voor de rangorde (het werd geprefereerd boven de directe LCA gegevens en de eco-indicator '95)
- Het concept of the EVR werd door de meerderheid van de niet-experts begrepen, maar de consequenties hiervan voor de eigen stijl van leven werden niet gemakkelijk aanvaard (de consumenten groep had er met name bezwaar tegen om *hun eigen* stijl van leven te beoordelen op grond van een parameter voor eco-efficiency)
- De groep van overheidsdeskundigen accepteerden het concept van de ecokosten echter niet direkt (zij gaven te kennen meer detailinformatie te willen); deze groep bleef vasthouden aan de reeds verworven kennis van LCA gegevens met de reeds

bekende eco-indicator, hetgeen in overeenstemming is met de theorie van Rogers over verspreiding van innovatie.

Uit het experiment valt verder op te maken dat:
- het aspect van duurzaamheid nauwelijks enige rol speelt bij de aankoopbeslissing, wanneer een consument een sterke voorkeur heeft voor een bepaald type product (op basis van andere aspecten, zoals de kosten/kbaten verhouding)
- het aspect van duurzaamheid echter een behoorlijk belangrijke rol kan spelen bij de beslissing wanneer er op andere gronden geen voorkeur bestaat.

De manier waarop de producten en diensten werden geselecteerd is weergegeven in Figuur J

le Filter: 2e Filter:
kwaliteit en prijs?   milieuvriendelijk?
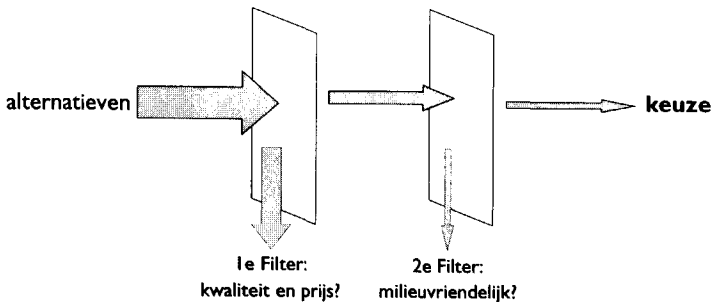
Fig. J: Het Dubbel Filter Model: milieugegevens spelen alleen een rol als secondair filter bij de aankoopbeslissing bij consumenten.

(Zie Hoofdstuk 8)

De weg naar duurzaamheid

De gecombineerde benadering van ecokosten en waarde laat nieuwe kansen zien om de 'factor 4' (of zelfs meer) in eco-efficiency te bereiken. De vereiste transformatie is echter verre van gemakkelijk.

Om het mechanisme van de vereiste transformatie te beschrijven is het '3 stakeholders model' geïntroduceerd. Zie Figuur K. Dit model toont de interactie tussen bedrijfsleven, overheid en consument/burger met betrekking tot duurzaamheid:
- burgers vragen de overheid zorg te dragen voor het lange termijn belang en te streven naar een duurzame samenleving
- overheden moeten zorgen voor de benodigde (en beperkende) regelgeving die tegelijkertijd voor het bedrijfsleven een zakelijk speelveld creëert met eerlijke concurrentie
- het bedrijfsleven moet inspelen op de korte termijn behoeften van de consument in termen van een maximale kwaliteit/prijs verhouding
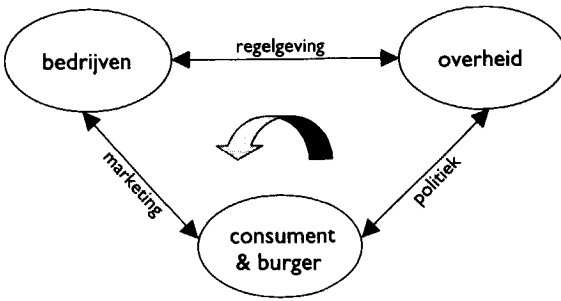
Fig. K: Het '3 stakeholders model' en de belangrijkste interacties.

Met betrekking tot de introductie van 'groene' producten legt het EWR model twee belangrijke issues bloot:
- met betrekking tot de product portfolio management strategie moeten bedrijven de EWR verbeteren van producten met een hoge waarde/kosten verhouding (dit is een betere strategie dan dat gepoogd wordt de waarde/kosten verhouding van producten met een goede EWR te verbeteren, zoals door veel milieukundigen en activisten voorgesteld wordt). Zie Figuur L.
- met betrekking tot marketing strategieën is het van belang te differentieren:
  - bij algemene handelsgoederen ('commodity products', waarbij het moeilijk is om te differentieren in prijs/kwaliteit) kan men lage ecokosten tot een differentiërende factor ('competitive edge') maken, waarbij prijs/kwalieit verhouding op het zelfde niveau moet blijven
  - bij speciale producten en producten die concurreren op kwaliteit kan men proberen de lage ecokosten het productimago te laten versterken, waarbij men er voor moet waken dat het milieu aspect niet bovenmatig wordt benadrukt, omdat consumenten primair de beste prijs/kwaliteit verhouding kiezen
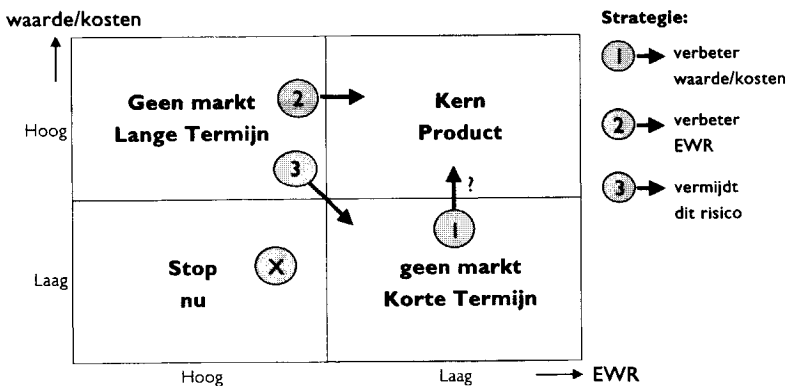
Fig. L: Product portfolio matrix voor de product strategie van een bedrijf.

In dit proefschrift wordt aangetoond waarom het zo moeilijk is voor de overheid om het bedrijfsleven in de richting te dwingen van duurzame producten , terwijl tegelijkertijd voor het bedrijfsleven de eerlijke concurrentie gehandhaafd blijft. Het geleidelijk verhogen van de belastingdruk op vervuiling zou in een gesloten economie werken, maar heeft het averechtse effect van het 'exporteren van milieuvervuiling' in het huidige systeem van open, wereldwijde handel.
Systemen van Verhandelbare Emissierechten in het bedrijfsleven, waaraan de overheid actief deelneemt, lijken de beste oplossing te bieden op nationaal niveau.
Op wereldniveau zou een systeem van Verhandelbare Emissierechten het juiste instrument kunnen worden om de CO_2 emissies te bevriezen op het huidige niveau. Snelle en drastische reductie van de emissies kan men echter van een dergelijk systeem nooit verwachten. Het doel kan men hier slechts stap voor stap (of beter: voetje voor voetje) bereikt worden.

Subsidies (of reductie van belastingen) op consumentenproducten zijn geschikt om de marktintroductie van innovatieve producten te ondersteunen, maar kunnen alleen gebruikt worden in markt niches, en alleen voor producten met een hoge EWR. Algemene subsidies (of reductie van belastingen) voor andere dan de voornoemde productcategorieën dient men te vermijden.

(Zie Hoofdstuk 9)

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Delft, 2001

Curriculun Vitae of Joost Geert Vogtländer

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hobbies: sailing, skiing and hiking, music

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1978 Management Development Course (Madoc), Shell, London
1987 HBG management course, de Baak, Noordwijk
1990 Top executive course, IMD, Lausanne

Career:
'72-'74 Nederlandse Melkunie (dairy products).
- project manager of the design and construction of the production plants
- member of the marketing team for the introduction of new products

'74-'90 Hollandse Beton Groep (HBG), Tebodin consulting engineers.
'74-'81 project manager in several big civil construction projects like the Eastern Scheld Surge Barrier (Oosterschelde dam), international airports, harbours, etc.
81-'86 head of the "Systems" Department of ICT projects for manufacturing and distribution.
International projects: England, Germany, Spain, Canada, Indonesia, Ned. Antillen
'86-'90 director of the Business Unit "Logistics and Manufacturing Technology": strategy development (including environmental economics), design of manufacturing and distribution systems, software engineering.
Projects for Shell, Unilever, KLM, DSM, Suiker Unie, Heineken, Akzo, Ahold, Henkel, BASF, Dow Chemical, Fuji Photo Film, and many others.

'90-'96 Bührmann Tetterode, after the merger KNP BT (8 billion $ multinational). Group vice president (lid van de hoofddirectie) responsible for the introduction of Operational Excellence:
- Total Quality Management: the introduction of of a new "corporate management culture"
- Productivity: improvement of the productivity by turnaround projects after the merger
- Logistics: optimisation of manufacturing and distribution systems
- Innovation: a new strategy for innovation of transport packaging
- Furthermore resposible for investments and desinvestments of real estate

'96-'02   Aiming Better BV, consultancy and interim management, managing director. Development of vision, strategy, organisation for companies, as well as the implementation of it. Reorganisations, transformations and product innovations. "Operational Excellence".
Personal assignments:
- interim management of a small consultants group in the field of environmental economics
- interim management of the introduction of a new 'Best Available Technology' invention
- projectmanager of the proposal of an innovative redesign of the A'dam-Paris High Speed Railway System, and redefining also the partnership between government and contracters
- profit improvement by reorganisation and transformation of a mid size consultancy group (500 consultants), international operating in the field of environmental engineering
- strategic business consultancy + project management of a big 'E-procurement' project of a mid size multinational (1.5 billion Euro).

Mid 1998 the PhD research project was started at the section of Design for Sustainability of the faculty Design, Construction and Production of the Delft Unviversity of Technology. End 1999 it was decided to expand this PhD research into the field of the faculty of Civil Engineering and Geosciences.

EVR in EcoScan 2.0

Joost Vogtländer and Suzanne Brink

Note: the EVR database 'EVR.mbd' and the example in Ecoscan 'Lemon-squeezerdef.epf'
can be downloaded from www.io.tudelft.nl/research/dsf.

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Tutorial for using the EVR database in EcoScan 2.0

Introduction

This tutorial helps you to work with the EVR (Eco-costs/Value Ratio) database in EcoScan. You will learn the basics of the EVR method while working with this guide.

When you start EcoScan a tutorial may open automatically. This tutorial is for other data-bases that accompany EcoScan. The biggest difference is that these databases calculate c millipoints, whereas the EVR database calculates on Eco-costs (in Euro). You can undo the automatic tutorial by clicking on the red button and by switching off the 'Start tutorial when opening' option in the Help menu.

For learning how to use the EVR database, only this PDF tutorial is available.

A. Preparations for using the EVR database in EcoScan 2.0

When you start EcoScan an empty PLC (Product Life Cycle) form appears automatically. On this form you will specify the product that you want to analyse. Before you can begin by filling in the production phase, you need to check three settings:

1   Are the dimensions of the form the same dimensions that the EVR database uses: Eco-costs (XEU), Value (XEU) and Kg (kg)?
2   Are the sheets 'Assembly', 'Marketing/Sales', and 'Transportation' added to the PLC form?
3   Is the EVR database mentioned in the Database menu?

If the answer is no, the default settings for the PLC form have not been adjusted for the EVR database. Close the PLC form and follow the instructions below.

A1. Adding sheets

Instructions
1   Choose New PLC form in the File menu.
2   Optionally fill in the general information in Step 1 of the PLC form settings.

3   tutorial for using the EVR database in EcoScan 2.0

3   Click on the Next button to go to Step 2 of the PLC form settings.
4   Click on the Add button.
5   Type 'Assembly'and press the enter key
6   Open the Image folder by clicking on the arrow on the right side of the menu. Select
    the hand by clicking on it.
7   Repeat steps 4 through 6 for adding the Marketing/sales sheet and the
    Transportation sheet. Choose the globe and the truck repsectively as icon instead of
    the hand.
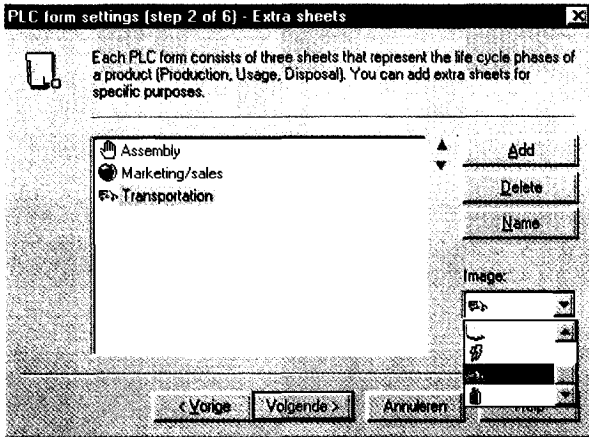
A2. Setting dimensions

Instructions

1   Click the Next button to go to Step 3 of the PLC form settings.
1   Click on the Delete All button.
2   Click on the Add button.
3   In the pop-up menu that appears click on Separate Column... .
4   Type 'Eco-costs' for Column Heading.
5   Select Value for Type of Data.
6   Type 'XEU'for Unit.
7   Select 0.00 for Precision.
8   Click on the OK button.
9   Repeat step 2 through 8 for adding Value (XEU, 0.00) and Kg (kg, 0.000)
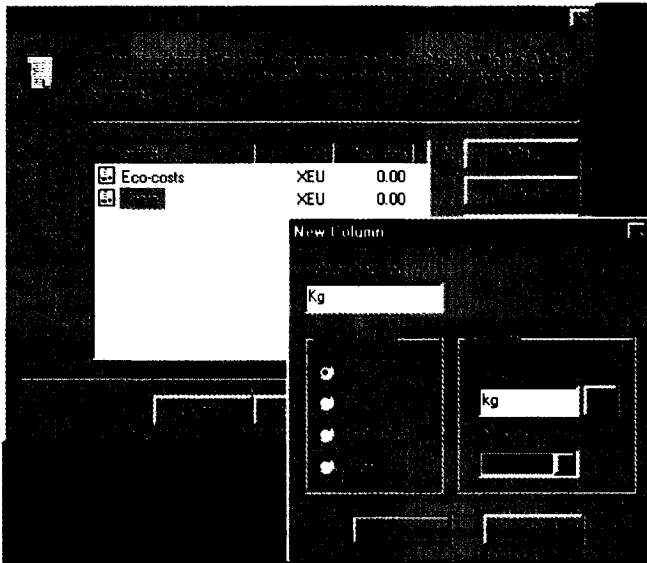
A3. Finishing the PLC form settings

Instructions

1 Click on the Next button to go to step 4 of the PLC form settings.
2 Select Automatic Disposal Switched On, Add Up Fractions (Recommended).
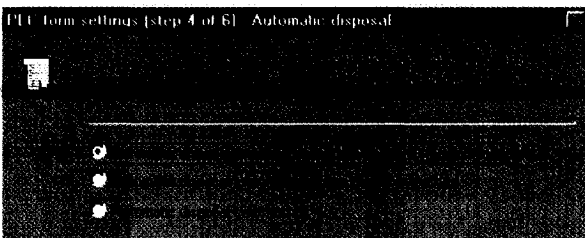
3 Click on the Next button to go to step 5 of the PLC form settings.
4 Select Automatic.
5 Type '1000'for Amount.
6 Select Other for Unit (click on the arrow on the right of it). Select Per Type... General.
7 Click on Times and click on the Insert button.
8 Type 'Squeezing lemons'for Action.
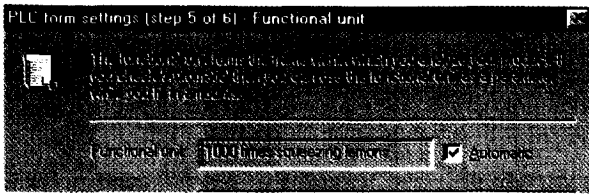
9 Click on the Next button to go to step 6 of the PLC form settings.
10 **Select Save These As The Default Settings.**
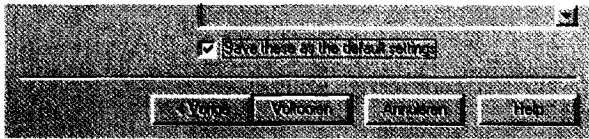
11 Click on the Ok button.

A4. Database menu

Instructions

1 Choose Open from the File menu.
2 Go to the EcoScan 2.0 folder and double click the Projects folder.
3 At File type select Database (*.mdb) to show all database files.
4 Select EVR.mdb and click on the Open button
5 Choose the Add to menu... command in the Database menu
6 Type 'EVR Database' and click on the OK button.
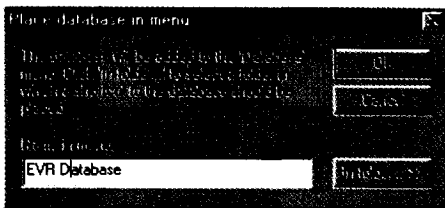
The EVR Database is now added to the Database menu.

B. Define components

In this tutorial the example of analysing a lemon-squeezer will be used to show how to work with the EVR database.

B1. Insert product

Instructions

1 Select the Production sheet by clicking on the Production tab in the PLC form.
2 Click on the New speed button:

A new product is added to the Production sheet.
3 Give the product a name by typing 'Lemon-squeezer'.
4 Press the Enter key.

B2. Insert components

The lemon-squeezer can be split into components.

Instructions

1 Select the product Lemon-squeezer by clicking on it with the mouse.
2 Click on the New speed button to add a new component to the Lemon-squeezer. Give the component a name by typing 'Housing'.
3 Press the Enter key.
4 Repeat step 1 through 3 for adding the components 'Juice bowl', 'Motor' and 'Packaging' to the lemon-squeezer.
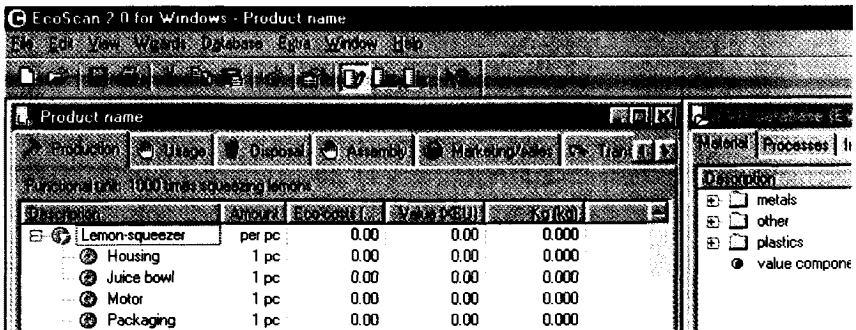
7 tutorial for using the EVR database in EcoScan 2.0

B3. Add materials

To specify the materials of the housing of the lemon-squeezer you need the EVR database.

Instructions

1 Choose the EVR Database command in the Database menu.
2 On the Material sheet of the database open the Plastics folder in the database by clicking on the plus sign in front of it.
3 Click on ABS and drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on the component Housing.
4 Type '240 g'to enter the amount of ABS for the housing of the lemon-squeezer.
5 Press the Enter key.
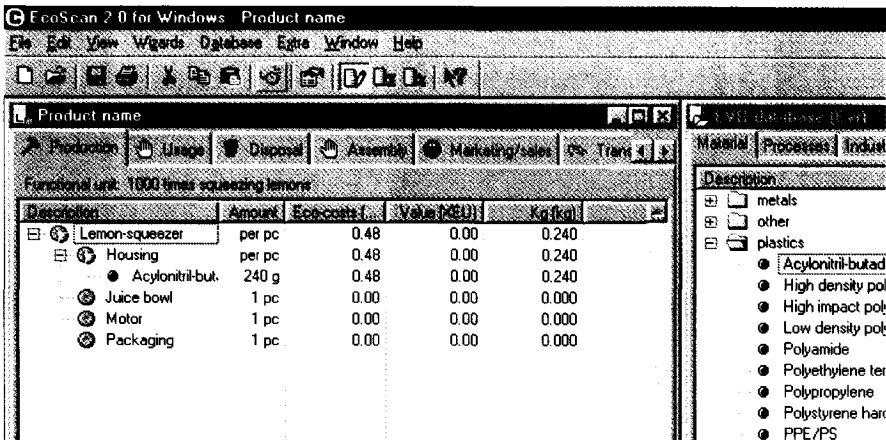
B4a. Add processes

You can specify which process was used to make the housing of the Lemon-squeezer.

Instructions

1 Select the sheet with processes by clicking on the Processes tab in the EVR database.
2 Open the Plastics folder by clicking the plus sign in front of the folder.
3 Click on 'Injection moulding general'and drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on the ABS of the component Housing.
4 Press the Enter button to accept the suggested 240 gram as the amount ABS for the process. If the process leads to material waste, do not forget to include that material (see aluminium for the motor in the illustration of B6.).

⊟ 🍋 Lemon-squeezer	per pc	0.50	0.00	0.240
⊟ 🍋 Housing	per pc	0.50	0.00	0.240
● Acylonitril-but	240 g	0.48	0.00	0.240
● Injection mou	240 g	0.02	0.00	0.000
🍷 Juice bowl	1 pc	0.00	0.00	0.000
🍷 Motor	1 pc	0.00	0.00	0.000
🍷 Packaging	1 pc	0.00	0.00	0.000

Aluminium
Plastics
- Calendering
- Extrusion blc
- Foil blowing
- Injection mo
- Injection mo
- Machining p
- Reaction inj
- Ultrasonic w

B4b. Add industry

The more generic processes can be found in the Industry sheet of the EVR database, e.g. for specifying the printing of the packaging.

Instructions

1 Select the Industry sheet in the EVR database by clicking on the Industry tab.
2 Click on Printing Industry and drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on the component Packaging.
3 Type '0.15' to enter the costs for printing in Euro. Press the Enter key.
   The Eco-costs for the printing of the packaging are now specified.

⊟ 🍋 Lemon-squeezer	per pc	0.55	0.15	0.240
⊟ 🍋 Housing	per pc	0.50	0.00	0.240
● Acylonitril-but	240 g	0.48	0.00	0.240
● Injection mou	240 g	0.02	0.00	0.000
🍷 Juice bowl	1 pc	0.00	0.00	0.000
🍷 Motor	1 pc	0.00	0.00	0.000
⊟ 🍋 Packaging	per pc	0.05	0.15	0.000
● Printing indus	0.15 XEU	0.05	0.15	0.000

general
- Agriculture cher
- Automotive indu
- Building materia
- Coating and ink
- Detergents indu
- Electrical indust
- Food industry
- Instrument and
- Leather industry
- Machine and ec
- Metal products
- Oil industry
- Paper industry
- Printing industry

ATTENTION

Always type '.' instead of ',' for fractional amounts (e.g. 0.70 instead of 0,70).

B5. Add component values

Apart from the weight and processing of the used materials, the value of each component needs to be entered.

Instructions

1   You will find the value components line in the Materials and Processes sheet of the EVR database.
2   Click on 'Value Component' and drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on the component Housing.
3   Type '1.30'for the value of the housing in Euro. Press the Enter key.

B6. Complete the product tree

You can repeat the previous steps for the components Juice bowl, Motor and Packaging. Use other materials and processes. The result should look approximately as follows, when using the industry costs guidelines of Appendix B:

C. Assembly

Producing the lemon-squeezer brings along overhead Eco-costs, which cannot be related directly to the processes and materials. On the Assembly sheet assembly costs can be specified. In paragraph D marketing and sales costs will be added.

Instructions

1 Select the Assembly sheet on the PLC form by clicking on the Assembly tab.
2 Click on the New speed button
   A new item is added to the Assembly sheet.
3 Type 'Assembly lemon-squeezer' and press the Enter key.
4 Select the Industry sheet in the EVR database by clicking on the Industry tab.
5 Open the General folder by clicking on the plus sign in front of it.
6 Click on Assembly in the Industry sheet, drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on Assembly Lemon-squeezer.
7 Type '4.00' to enter the assembly costs of the lemon-squeezer in Euro. If the costs are not known use the table Industry Costs Guidelines in Appendix 2.
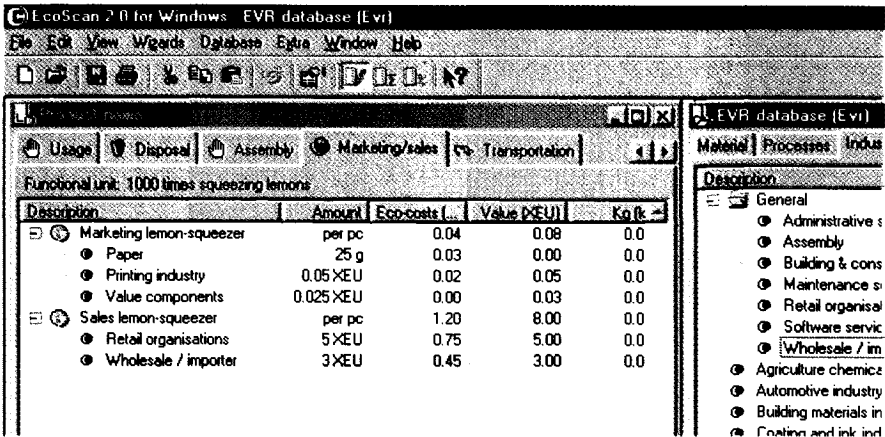
```
[~] EcoScan 2.0 for Windows - Product name
File  Edit  View  Wizards  Database  Extra  Window  Help
```

Product name				
Production	Usage	Disposal	Assembly	Marketing/sales	Tran
Functional unit: 1000 times squeezing lemons				
Description	Amount	Eco-costs [..	Value [XEU]	Kg [kg]
⊟ Assembly lemon-squeezer	per pc	0.80	4.00	0.000
● Assembly	4 XEU	0.80	4.00	0.000

Material | Processes | In
Description
⊟ general
  ● Administrativ
  ● Assembly
  ● Building & c
  ● Maintenanc

D. Marketing and sales

Instructions

1 Select the Marketing+sales sheet on the PLC form by clicking on the Marketing+sales tab.
2 Click on the New speed button
   A new item is added to the Marketing + sales sheet.
3 Type 'Sales lemon-squeezer' and press the Enter key.
4 Select the Industry sheet in the EVR database by clicking on the Industry tab.
5 Open the General folder by clicking on the plus sign in front of it.
6 Click on Retail organization in the Industry sheet, drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on Sales Lemon-squeezer.
8 Type '5.00' to enter the retail costs of the lemon-squeezer in Euro.
9 Add other marketing + sales items to the Marketing + sales sheet. The result may look like this:


```
[~] EcoScan 2.0 for Windows - EVR database (Evr)
File  Edit  View  Wizards  Database  Extra  Window  Help
```

Usage	Disposal	Assembly	Marketing/sales	Transportation
Functional unit: 1000 times squeezing lemons				
Description	Amount	Eco-costs [..	Value [XEU]	Kg [k
⊟ Marketing lemon-squeezer	per pc	0.04	0.08	0.0
● Paper	25 g	0.03	0.00	0.0
● Printing industry	0.05 XEU	0.02	0.05	0.0
● Value components	0.025 XEU	0.00	0.03	0.0
⊟ Sales lemon-squeezer	per pc	1.20	8.00	0.0
● Retail organisations	5 XEU	0.75	5.00	0.0
● Wholesale / importer	3 XEU	0.45	3.00	0.0

Material | Processes | Indu
Description
⊟ General
  ● Administrative s
  ● Assembly
  ● Building & cons
  ● Maintenance s
  ● Retail organisa
  ● Software servic
  ● Wholesale / im
● Agriculture chemic
● Automotive industry
● Building materials in
● Coating and ink ind

E. Transport

On the Transportation sheet all transport that is needed for the lemon-squeezer in its life-time will be specified.

E1a. Transportation

First the transportation from the factory to the wholesale will be analysed.

Instructions

1 Select the Transportation sheet on the PLC form by clicking on the Transportation tab.
2 Click on the New speed button.
3 Type 'Transport factory-warehouse' and press the Enter key.
4 Select the Transport sheet in the EVR database by clicking on the Transport tab.
5 Click on Truck + Trailer (net 24 ton in the Road Transport folder) and drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on 'Transport factory-warehouse'.
6 Type '1000' to enter the amount of kilometres that the truck had to drive from the factory to the warehouse. Press the Enter key.

ATTENTION

You have now calculated the Eco-costs for the whole truck. To calculate the share of the lemon-squeezer you are analysing, calculate how many lemon-squeezers fit in the truck. For specifications on pallet-sizes and truck-sizes see Appendix 1.

If the size of the packaging is 20 x 20 x 30 cm, Appendix 1 tells us that one pallet comprises 220 lemon-squeezers. The truck comprises 26 pallets. Therefore the Eco-costs of the truck + trailer must be divided by 220 x 26 = 5720.

There are two ways to include this division in the Transportation sheet:

1 Calculate 1000 / 5720 = 0.175
   Double-click the amount of the truck + trailer and type '0.175' or:
2 Double-click the amount of Transport factory-warehouse and
   type '0.000175'(= 1 / 5720)

The lemon-squeezer is now held responsible for 1/5720th of the Eco-costs of the truck transport.

E1b. Calculate transportation distance

If you want EcoScan to calculate the distance for you, you can use the Transportation wizard.

Instructions

1   Select the Transport sheet in the EVR.
2   Click on Distance Dummy Transport Wizard and drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on 'Transportation factory-warehouse'. Press the Enter key
3   Select the Distance Dummy Transport Wizard on the PLC form by clicking on it.
4   Choose the Transportation wizard command in the Wizards menu.
5   Click on the From button.
6   Open the Europe folder, open the Italy folder, and select the city Milan. Click on the OK button.
7   Click on the To button.
8   Open the Europe folder, open the Netherlands folder, and select the city Rotterdam. Click OK.
9   In Amount To Be Transported type '1' and change the dimension into ton (t)
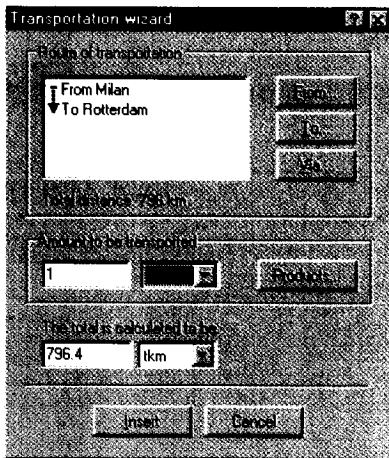
10 Click Insert.
11 Double-click the amount for the Truck + trailer on the PLC form.
12 Enter the amount calculated by the transportation wizard, in this case '796.4'

ATTENTION
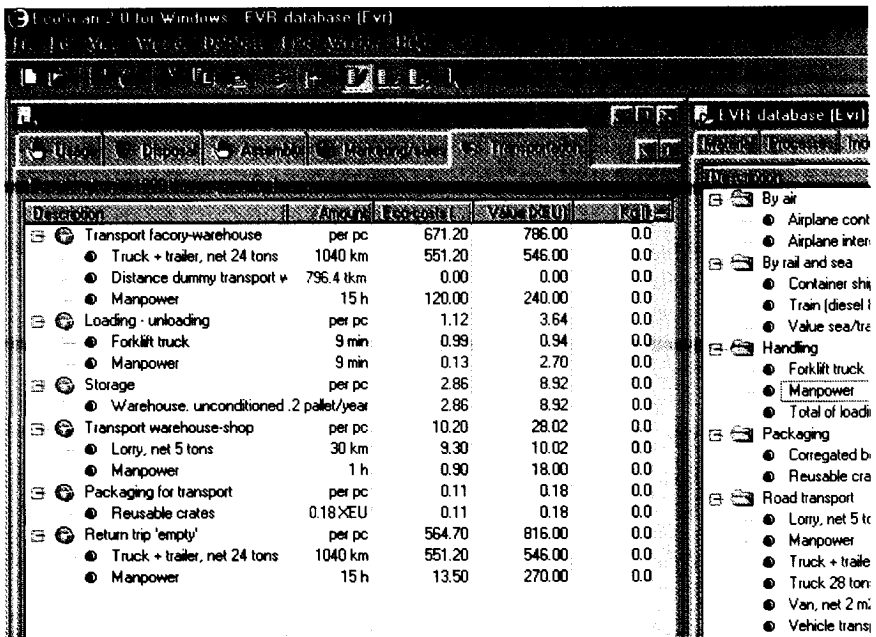
The transport wizard calculates the distance in a straight line. So use the 'VIA' option to make the calculation more accurate, or add 20-30% to approximate the real distance (for transport by sea, always define the distance using 'VIA').

You have now calculated the Eco-costs for the whole truck (see ATTENTION on the previous page) so, if you have not done so yet, double-click the amount of Transport factory-warehouse and type '0.000175'to calculate the data for one lemon-squeezer.

The lemon-squeezer is now held responsible for 1/5720th of the Eco-costs of the truck transport.

E2. Complete Transportation sheet

Other facilities of transport are listed in the EVR database as well. Warehouse, fork-lift-truck, transport packaging, manpower etc. You can repeat steps E1a and E1b for these aspects, and use option 2 for calculating the share in transport for only one lemon-squeezer (with help of Appendix A). Mind the difference in the applied dimensions: make a choice based on the data you have access to. When you are done with filling in the Transportation sheet, the result may look as follows:

The screenshot shows:

EcoScan 2.0 for Windows - Product name

File Edit View Wizards Database Extra Window Help

Product name

Usage | Disposal | Assembly | Marketing/sales | Transportation

Functional unit: 1000 times squeezing lemons

Description	Amount	Eco-costs [...]	Value (XEU)	Kg (k
Transport facory-warehouse	0.000175 pc	0.12	0.14	0.0
Loading - unloading	0.0045 pc	0.01	0.02	0.0
Storage	0.0045 pc	0.01	0.04	0.0
Transport warehouse-shop	0.00045 pc	0.00	0.01	0.0
Packaging for transport	0.25 pc	0.03	0.04	0.0
Return trip 'empty'	0.000175 pc	0.10	0.14	0.0
Total for this phase:		0.27	0.39	0.0

No item selected

EVR database (Evr)

Material | Processes | Ind

Description

By air
• Airplane conl
• Airplane inter
By rail and sea
• Container shi
• Train (diesel
• Value sea/tr;
Handling
• Forklift truck
• Manpower
• Total of loadi
Packaging
• Corregated b
• Reusable cra
Road transport
• Lorry, net 5 t
• Manpower
• Truck + traile
• Truck 28 ton
• Van, net 2 m
• Vehicle trans
• Vehicle trans
• Vehicle trans
• Vehicle trans

Manpower, forklift tr;
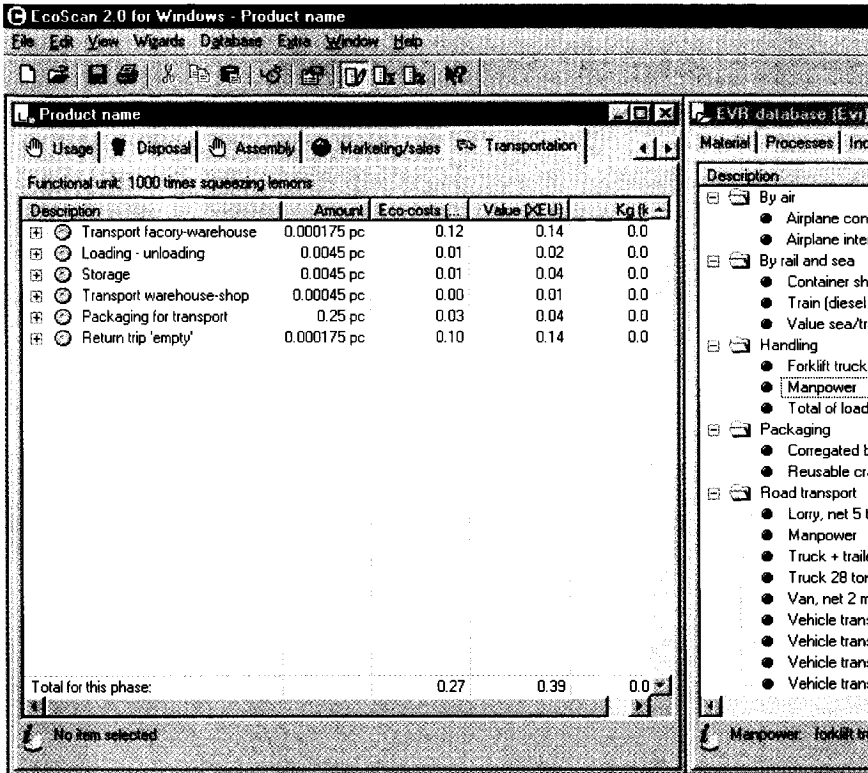
F. Use

F1. Enter the functional unit

To specify the use phase of the lemon-squeezer the total use must be estimated, e.g. to calculate the correct amount of energy consumption. It will be entered in the PLC form as Functional Unit.

Instructions

1   Click on Functional Unit at the top of the PLC form.
2   Type '2000' for Amount
3   Select Other... for Unit. A dialog box appears.
4   In Per Type 'General' at the top of the list.
5   Select 'Times' for Unit and click on Insert.
6   Type 'squeezing lemon halves' for Action.

7   Click OK.
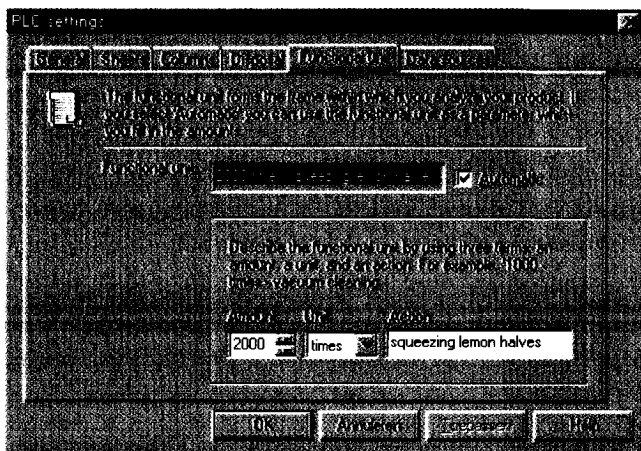
At the top of the PLC form the new functional unit will appear.

F2a. Define usage aspects

Now the usage aspects of the lemon-squeezer can be specified on the Usage sheet.

Instructions

1   Select the Usage sheet on the PLC form by clicking on the Usage tab.
2   Click on the New speed button.
3   Type 'Energy consumption' and press the Enter key.
4   In the EVR database select the Use sheet by clicking on the Use tab.
5   In the Electricity folder click on Electricity (Domestic low) and drag it (with the left-hand mouse button pressed down) to the PLC form and drop it on Energy consumption.

ATTENTION

There are 3 items named Electricity (Domestic low). They differ in dimension. Choose the dimension of which you know the amount to be most accurate.
In this tutorial we use the one that is specified in kWh.

6   Type '1.5' to enter the amount of kWh the lemon-squeezer uses in its entire life.

F2b. Calculate energy consumption

To calculate the total energy consumption for the entire life cycle of the lemon-squeezer the Consumption wizard can be used together with the functional unit. The lemon-squeezer can squeeze 4 lemon halves per minute.

Instructions

1 Select the line Electricity (domestic low) on the Usage sheet of the PLC form.
2 Choose the Consumption wizard command in the Wizards menu.
3 Change the Switch On Frequency to '15 s per times'.
4 Change the Product power to 200 W.
5 Click Insert.
   The wizard has calculated that the lemon-squeezer uses 1.7 kWh in its total lifetime.
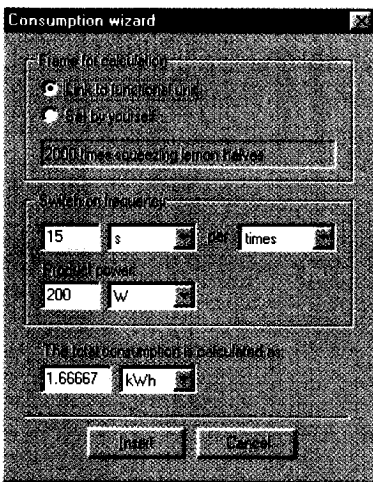
G. Setting the disposal mode

You can set the disposal mode on the Disposal sheet.

Instructions

1 Select the Disposal sheet on the PLC form by clicking on the Disposal tab.
2 Click on the plus sign in front of the lemon-squeezer to view all materials that are to be disposed.
3 Click on the line of the Lemon-squeezer in the Scenario column. A dotted frame appears around Domestic waste.

ATTENTION

When reopening the PLC form, the 'scenario' column may have disappeared. To collect it again place the cursor in between Amount and Eco-costs, wait for the special cursor (a double line with an arrow on each side) to appear and click. The column will show again.

4   Click within the frame again. Choose the Municipal waste disposal scenario.
5   Click on the Marketing Lemon-squeezer line in the Scenario column. A dotted frame appears around Domestic waste.
6   Click within the frame again. Choose the Recycling waste disposal scenario.
    You are done with filling in the disposal aspects. The result looks as follows:


H. Display results graphically

All the sheets have been filled in. You can now display the results in a graph.

Instructions

1   Select the PLC form.
2   Choose the Bar chart command in the Extra menu.
3   Click on the ... button and select Eco-costs and Value.
4   Click on the OK button.
5   Click on the Yellow Arrow button.
6   Click the bar in the graph that represents the production phase.
7   Click the bar in the graph that represents the lemon-squeezer.

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8 Click the bar in the graph that represents the motor.

9 The same results can be seen in pie charts by choosing the Pie chart command in the
   Extra menu.
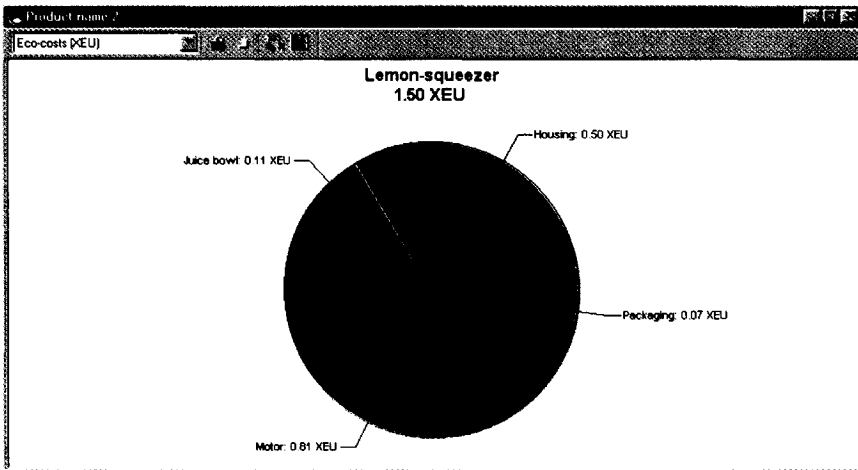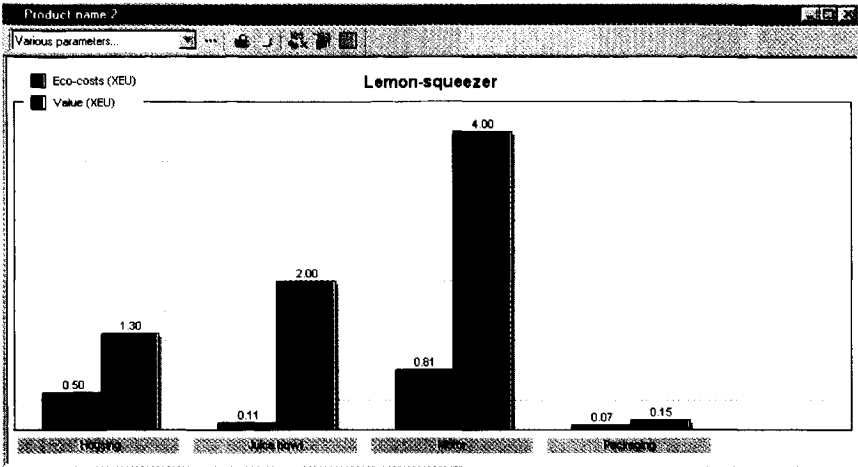
I. Conclusions

Now you can draw conclusions on the design you have specified:

a. You may conclude that the Eco-costs of marketing and sales are considerable in com-
   parison with the other phases in the Life Cycle; so you might want to analyse it in

more depth to achieve the same marketing and sales value with minimum Eco-costs.

b. Although transportation is not adding much to the Eco-costs here (as is generally the case for high value products), you may conclude that it is better to avoid transport packaging. This could be done by making the primary packaging strong enough to carry the maximum weight at the lowest layer on the pallet (removable crates are the wrong choice for transport packaging for long distances because of the empty return transport leg).

J. Save results

Instructions

1 Select the PLC form by clicking on it.
2 Choose Save in the File menu.
3 Type 'Lemon-squeezer' for Filename.
4 Choose PLC form (*.epf) for Save as.
5 Choose a location on your PC, for example in the Projects folder in the EcoScan 2.0 folder.
6 Click on the Save button

This tutorial has taught you roughly how to use the EVR database while carrying out a Life Cycle Analysis with EcoScan 2.0. Not all functions and possibilities of EcoScan have been shown. They are described in the online Help of EcoScan or the user guide that comes with the software. More in-depth information on the EVR method can be found in Part 2 of this user guide. Also, when clicking on a database item, general information and hints are shown below in the status-bar.

Enjoy working with EVR in EcoScan!

tutorial for using the EVR database in EcoScan 2.0

The EVR model

Introduction

In Part 1 of this manual you have become acquainted with the EVR database of EcoScan and the way in which you can make calculations. Perhaps you already wondered why the calculation of the lemon- squeezer was structured as it was. Perhaps you wondered 'what if?' when you had data available in a different form (e.g. you only knew the transport costs, without any further details). Perhaps you wondered how to make a calculation on a certain type of service (a holiday trip or maintenance service), which does not allow you to start with the 'kilograms required for production', and which has no simple chain from 'production' to 'end of life'. (In service systems several chains often interact in a complex way).

Part 2 explains how to structure the Life Cycle System of a product, a service or a 'bundle of products and services' in order to analyse it in EcoScan. Although EcoScan was origin- ally designed to cope with the Life Cycle Analyses (LCA) of products only, EcoScan can do more for you, when you apply the EVR model and the EVR database! It can handle com- plex 'bundles of products and services' (also called PSS, Product Service Systems).

1. The LCA structure for 'products'

First, we will look at the LCA structure for products like the lemon-squeezer, which have a life cycle chain from 'production' to 'end of life' that is easy to define, see Figure 1.

Components

The production of components is defined in the Production sheet of the Product Life Cycle form (PLC form) in EcoScan. Most of the materials (from the Material sheet of the EVR database) enter our Life Cycle System here. However, note that materials can also be used in other steps of the Life Cycle System (in the example of the lemon-squeezer: the glossy brochure for marketing). The Production sheet is also used to define the primary production processes of the components, which can be selected from the Processes
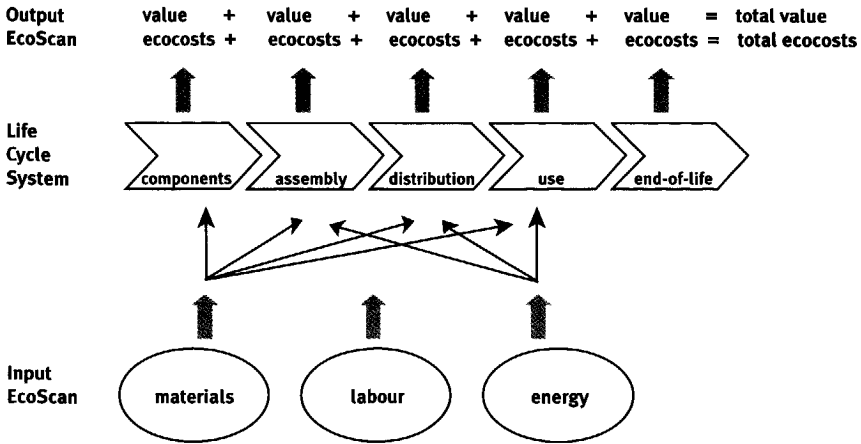
| Output EcoScan | value + ecocosts + | value + ecocosts + | value + ecocosts + | value + ecocosts + | value = ecocosts = | total value total ecocosts |

Figure 1. Calculation structure for 'products'

sheet of the database. Since the value (the price) of the materials and the primary pro-
duction processes are not provided in the database, you must add the value of the com-
ponents in this Production sheet as well.
The data from the Material sheet and from the Processes sheet include the transport of
materials and the energy required for the processes. These data do not incorporate the
Eco-costs of labour (light, internal climate, commuting) nor the Eco-costs related to the
depreciation and maintenance of equipment, buildings etc. You must add these
elements.

When you do not have detailed information on the production processes and other neces-
sary details, you can use the Industry sheet instead of the Processes sheet, to cope with
the eco-effects in the LCA. The Industry data include the labour, the equipment and the
building. In the Value column of the Industry sheet, the Added Value of that industry is
given (the added value of a company is the total sales value per annum minus the total
purchase value per annum).

Assembly, Marketing and Sales
The assembly of the product is defined in the Assembly sheet in your PLC form in
EcoScan. In most cases, the marketing of a product is organized by the same company
that assembles the product (cars, computers, domestic appliances, etc.) but it is deliver-
ed by a third party. Marketing is therefore defined separately. Note that maintenance
(after sales service) has to be specified under Marketing and Sales as well.

special topics concerning the EVR database   24

Transportation
The transport is to be defined in the Transportation sheet by means of the data in the Transport sheet of the database. This can be done in either of the following ways:
a. By defining the transport chain in detail (as it is partly shown in the example of the lemon-squeezer)
b. By applying the costs data of the transport chain directly (using the Transportation data with financial dimensions)
It is a widespread misunderstanding that the calculations made on the basis of kilograms are more accurate than the calculations based on costs data. Especially in the case of transport systems, where the so called 'allocation' of LCA data is a major issue, calculations based on the Eco-cost/ Value Ratio (EVR) are at least as accurate as the classical LCA approach on the basis of kilograms (Vogtländer et al. 2000) and are less complex.

Use
Energy consumption typically dominates the usage phase of the Life Cycle. For your convenience, the energy data in the Energy sheet of the database are provided on the basis of:
- GJ
- kWh and XEU for electricity (domestic as well as industrial)
- Litres and XEU for fuel for cars (gasoline as well as diesel)

End-of-Life
The End of Life calculation in the model is based on the total amount of materials used in the product. It is added to your PLC form only when you enter materials from the Material sheet of the database.
You can specify the type of 'End of Life' by dragging your choice from the End of Life sheet to the PLC form.
There are two sets of data:
a. NOH data based on the NOH scenarios for end of life
b. EVR data based on the EVR scenario for end of life

The NOH data takes into account whether the waste is recycled or used to generate electrical energy, the latter resulting in negative emission levels.

In the End of Life scenario of the EVR model, there are no negative emission levels at the end of a product life. Recycling is taken into account at the stage where materials are selected for the new product, and therefore cannot be included again at the end of a product life. Otherwise recycling would count twice. It is your own choice which calculation

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philosophy you want to apply: although you are calculating with the EVR database, it is allowed to apply the NOH scenarios if you wish.

Note: when applying the EVR data on EoL, switch off the Automatic Disposal Function in the Properties command under the File menu, in the Disposal tab.

2. Functional units

The 'functional unit' forms the basis on which you will compare alternative solutions. It must describe the functional performance of your product and/or service. It also determines the boundary limits of the system which you are going to analyse. Therefore the choice of the functional unit determines the answer to the question 'what is the best choice for sustainability?' to a great extent! Needless to say that you must carefully con - sider the choice of the functional unit and its consequences before you start your analyses.

Example 1

When you are asked to advise on a 'sustainable truck+trailer', you have several levels on which you can define your functional unit:

1   the truck+trailer itself
2   the truck+trailer per kilometer
3   the volume to be transported per kilometer
4   the weight to be transported per kilometer

Apart from the fact that you will try to minimize the fuel consumption in all cases (aerodynamics, motor efficiency, tyres), you will be focussed on different improvements for each of the four cases:

1   when your functional unit is the truck+trailer itself, you will be focussed on the use of materials with low Eco-costs
2   when your functional unit is defined per kilometer, you will probably be focussed on extending the life time of the truck
3   when your functional unit is volume per kilometer, you might discover that a new design for maximum volume in the trailer will be a good design strategy
4   when your functional unit is weight, you will focus on minimum empty-weight (on the European roads there is a maximum weight of 40 tons, so a light truck allows for a high 'payload' and therefore a low value of 'tonkm / litre diesel')

Example 2

In the field of analyses of passenger transport systems, the 'occupancy rate' of the vehicles is a crucial factor:
-   for commuting, there is only one passenger in the car (the driver)
-   for holidays, the car is occupied by 3-4 people
-   what is the occupancy rate of a train (during rush-hour or during the weekends)?
-   what is the occupancy rate of a plane (and is it realistic to compare a full plane with a half-empty train)?

And with regard to the system boundaries:
-   is infrastructure (road, rail) to be included and how?
-   Which functional unit would you choose in which situation?

3. The LCA structure for 'services' and 'product service combinations'

When you have determined your functional unit (the first step in an LCA) you have to define which 'product systems' and 'services systems' are required to fulfil the functional performance.

When you are analysing a 'product', you can start right away with a break-down of:
-   the materials which are applied in the product
-   the processes which are needed to manufacture these materials
-   the assembly of the components

When you are, however, analysing a 'service', you miss the list of materials and components to start with. You need another approach: for each system you have to determine which elements (objects) are involved and which activities take place.

The easiest way to tackle this problem is:

Step 1.   Make a description of the process in terms of a sequence of activities
Step 2.   Make a list of system elements which are involved in the sequence of activities
Step 3.   Analyse the 'direct' Eco-costs and the 'indirect' Eco-costs of each element
Step 4.   'Allocate' the Eco-costs of Step 3. to the activities of Step 1

Example 3

The analyses of a typical transport system with the function to transport a product from A to B in reusable plastic crates.

Step 1

List of activities (typical):

1   pallets with full crates have to be transported from the storage or filling area to the

dispatch area by forklift trucks

2   pallets have to be loaded by forklift trucks
3   the truck is driving from place A to place B
4   pallets are unloaded by forklift trucks
5   pallets with empty crates are loaded with forklift trucks
6   the truck is driving from place B to place A
7   pallets with empty crates are unloaded with forklift trucks
8   pallets with empty crates are transported to storage by forklift trucks

So there are three main activity groups:
-   transport
-   loading and unloading
-   storage

Step 2

List of main system elements:
A. the truck
B. the forklift truck
C. the warehouse for storage
D. the reusable crates
E. the road infrastructure (if you want to include that in your analyses)

Step 3

For each of the elements of Step 2 the Eco-costs must be determined in terms of:
-   the object (e.g. the truck, the warehouse)
-   the 'direct' energy requirements (i.e. fuel, electricity)
-   the related 'direct' labour (e.g. the forklift truck driver)
-   'indirect costs' like insurance, interest, etc.

Each object has its own life cycle ('value chain') creating 'indirect' Eco-costs for:
-   the materials required to make the object
-   the manufacturing
-   the distribution (of the truck and the forklift truck)
-   the use and the maintenance (for the crates: cleansing)
-   the 'end-of-life'

Step 4

The Eco-costs calculated in Step 3 must be allocated to the list of activities of Step 1.

In the example of the lemon-squeezer you tackled this problem for a simple case. Now you see that the problem increases considerably in complexity for 'real life' situations. The next chapter explains how this problem is tackled by means of a 'costs break-down structure', combined with EVR (Eco-costs / value ratio) data.

4. Tackling LCA problems by means of costs break-down structure and EVR

In costs accounting (= determining the price of a product or a service), business people have to tackle a problem which is similar to the problem described in the previous chapter. They use a special methodology, which is called Activity Based Costing (ABC), to deal with the same difficulties in terms of system complexity and allocation problems. The result of ABC is a 'costs break-down structure', showing all important cost elements of the total costs of a product and/or service.

Usually, the easiest way to start the LCA of a service (or a product service combination) is a costs break-down structure, since;
- often the cost break-down structure is already known to the business people involved
- we are all acquainted with 'thinking in terms of money' from experience in our daily life.

Example 4
The same transport system as described in Example 3.

Cost elements in the transport chain:
A. the truck for transport (costs are a function of required distance and time)
B. the forklift truck for loading and unloading (costs are a function of required time)
C. the warehouse for storage (storage costs are a function of pallets and time)
D. the reusable crates (costs are a function of price and number of round trips)
F. the road infrastructure (if you want to include that in your analyses)

You can use the data in the Transport sheet in two ways:
- Apply the EcoScan data to calculate both costs and Eco-costs. You need to know the transport distance and speed, the time required for the forklift truck, the number of pallets and the period of time that they have to be stored in the warehouse, and the price of a crate plus the number of round trips. See Figure 2.
- Apply the EcoScan data to calculate the Eco-costs when the cost data is known for transport, loading/unloading, storage and use of crates. See Figure 3.

There is no need to calculate in 'kilogrammes' since there appears to be a linear

figure 2: Applying the EcoScan data to calculate both costs and Eco-costs.

figure 3: Applying the EcoScan data to calculate the Eco-costs when the cost data are known.

relationship between the costs (the Value) and the Eco-costs for specific sets of activities and elements. For such a set of activities and elements the so called Eco-costs/Value Ratio (EVR) is fixed. The EVR has been calculated (applying the normal 'mass based' LCA calculation techniques) for a lot of activities and elements, and stored in the EVR database. For more details see (Vogtländer et al., 2000a).

5. The output and the meaning of the EVR

The output of the EcoScan calculation is twofold:
- the Eco-costs
- the Value

The standard output is shown on a bar chart, however it is more instructive to print the output in a form as given in Figure 4.
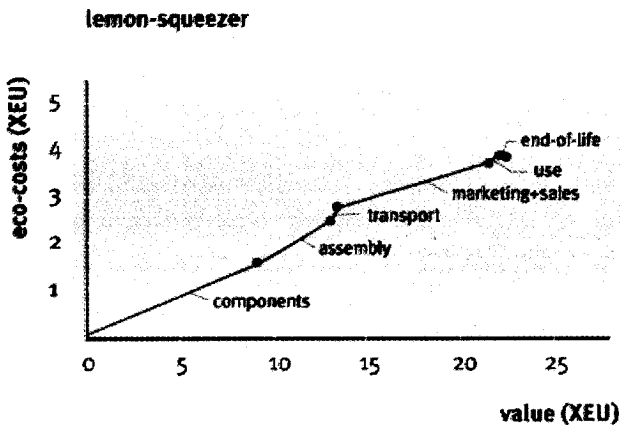
lemon-squeezer

Figure 4: the lemon-squeezer results in a Eco-costs = f (costs) graph

Products which have a high Value combined with low Eco-costs are fit for use in a sustainable society. They combine a high level of economic prosperity with a low burden to the earth. In other words: products with a low EVR have a high eco-efficiency (Vogtländer, 2000c).

Figure 4 shows the strategies for better product design:
- reduce Eco-costs of materials and processes
- avoid elements with a high EVR like transport and energy consumption

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- try to increase the added value of elements with low Eco-costs by extra quality and service

6. How to calculate other Eco-costs.

The Eco-costs of a material equals the sum of the "pollution prevention costs '99" and the "materials depletion costs '99" (Vogtländer et al., 2000a), in formula:

eco-costs '99 = pollution prevention costs '99 + materials depletion costs '99

The materials depletion costs '99 is calculated as follows:
- the materials depletion costs '99 is set equal to the market value of the raw material when the material is not recycled
- when a fraction f of the sourced material is recycled, a factor (1-f) is applied to the market value of the raw material to calculate the materials depletion costs '99

Therefore:
materials depletion costs '99 = 'market value of the raw material'x (1-f)

The underlying assumption is that the (average) market value of the raw material reflects the fact as to whether the material is scarce or hard to find and/or mine (e.g. platinum, gold, silver), or whether that will happen in the foreseeable future. For details see (Vogtländer et al., 2000aa). In line with the general philosophy of the EVR model, ethanol based on bio mass is used as raw material for plastics. This price is estimated at 0,6 Euro/kg.

You can calculate the pollution prevention costs '99 of a material (or a process) by means of a simple spread sheet, when you have gathered the LCA data. The methodology (Vogtländer et al., 2000d) is quite similar to the methodology of the calculations of the Eco-indicator '95 in Simapro.

Example 4.
Calculation of the pollution prevention costs '99.
Wood based chlorine free bleached white printing paper, quantity 1 kg.
LCA data from BUWAL Oekobilanz von Packstoffen, 1990, Bern
For a table of characterization factors see (Vogtländer et al., 2000d)

column 1	2	3	4	5	6	7	8
pollutant	class	amount (kg)	characterisation factor	3 x 4 'kg equ.'	poll. prev. costs (euro/kg)	5 x 6 poll. prev. costs '99 (euro)	sum of 7 total poll prev costs'99 (euro)
ammonia	acidification	3,63E-06	1,88	6,82E-06			
HF	acidification	1,20E-08	1,6	1,92E-08			
NOx	acidification	5,47E-03	0,7	3,83E-03			
SO2	acidification	1,22E-02	1	1,22E-02			
			subtotal:	1,60E-02	6,4	1,03E-01	
ammonia	eutrophication	3,63E-06	in acidification				
NOx	eutrophication	5,47E-03	in acidification				
COD	eutrophication	4,46E-02	0,022	9,81E-04			
NH3	eutrophication	1,03E-06	0,33	3,40E-07			
			subtotal:	9,82E-04	3,05	2,99E-03	
CO2	greenhouse ef.	1,61	1	1,61E+00			
N2O	greenhouse ef.	3,59E-04	270	9,69E-02			
			subtotal:	1,71E+00	0,114	1,95E-01	
Hg in air	heavy metals	1,90E-08	1	1,90E-08			
Hg in water	heavy metals	1,00E-09	10	1,00E-08			
			subtotal:	2,90E-08	680	1,97E-05	
aldehydes	summer smog	1,02E-05	0,443/0,398=1,113	1,14E-05			
CxHy	summer smog	6,98E-03	0,398/0,398=1,0	6,98E-03			
methyl mercaptane	summer smog	1,85E-04	0,377/0,398=0,947	1,75E-04			
			subtotal:	7,16E-03	50	3,58E-01	
dust (SPM)	winter smog	4,57E-03	1	4,57E-03			
SO2	winter smog	1,22E-02	in acidification				
			subtotal:	4,57E-03	12,3	5,62E-02	
Total pollution prevention costs '99, 1 kg paper :							7,14E-01

Literature

Vögtlander, 2000a	Vögtlander, Brezet, Hendriks: The Virtual Eco-costs '99, a single LCA-based indicator for sustainability and the Eco-cost/Value Ratio (EVR for economic allocation)
Vögtlander, 2000b	Vögtlander, Brantjes: the Eco-costs, the costs and the EVR of road transport of consumer goods.
Vögtlander, 2000c	Vögtlander, Brezet, Hendriks: The EVR model as a tool to optimise a product design and te resolve strategic dilemnas.
Vögtlander, 2000d	Vögtlander, Bijma: The virtual pollution prevention costs '99, a single LCA-based indicator for emissions, International Journal of LCA, Volume 1, January 2000.

Appendices

Appendix A. Sizes of pallets and boxes in efficient transport systems

Since transport is an important link of the chain, the packaging of a product must be optimized. The optimum packaging design has to meet two criteria:
- fit to the product
- fit to the transport carrier

This Appendix shows the logic of sizes which fit road transport systems.

The majority of the transport pallets are standardized (and are shared in the so called European pallet pools). There are two major standards:
- 1,20 m x 1,00 m (most of the European standard pallets)
- 0,80 m x 1,00 m (the so called "Euro pallet", which is less popular than the standard pallet)

The standard European trailer (length 13,60 m, width 2,50 m, height 2,70 m) can carry 26 standard pallets. The total maximum pay-load of such a trailer is 24 tons, so the weight of an average pallet must be somewhat less than 1 ton.

The logical box or crate size for the standard pallet is 0,60 m x 0,40 m (5 boxes per layer). Each subsequent layer of the box grid alternates in the opposite direction, providing a coherent pile of boxes, see Figure 5.

Fruit and vegetables are transported very efficiently in plastic crates (height of one layer 20 cm), or in board boxes (0,40 m x 0,30 m, height 0,20 m).
The height of a full pallet is normally not more than 2,40 m to allow for easy loading and unloading, accommodating 11 layers (the height of the empty pallet itself is 0,15 m).

There is a tendency in the food industry to (re)design consumer packaging (bottles, boxes, etc.) so that they fit in the above standard crate size (the height of a crate for food
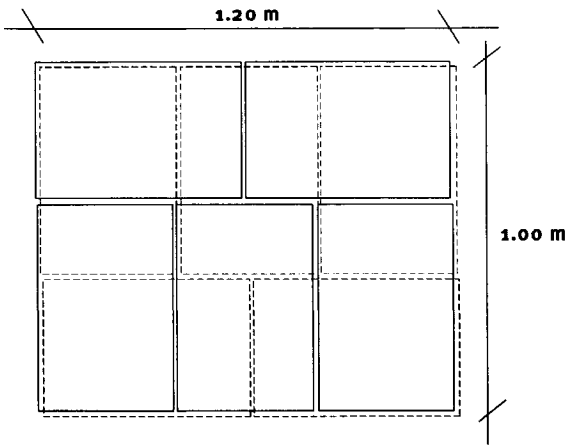
Figure 5. Two layers of boxes (0,60 m x 0,40 m) on a standard pallet (1,20 m x 1,00 m)

other than fruit and vegetables is not standardized). This is stimulated by the big retailers (Albert Heijn, Sainsburry, Tesco, Tengelmann, Aldi, etc.). Transport packaging for other products is less standardized, but will follow soon when these products will be channelled to the consumer markets by big specialized retailers as well.

Appendix B. Industry costs guidelines

Business people know the cost structure of their products. For students and other desig-
ners outside the business, it is often hard to find out in advance what the cost structure
of a product or service is. The easiest way to find out is via Economic Statistical Institutes
(CBS for The Netherlands). These Institutes normally have data available on Added Value
per economic sector (start in The Netherlands with: "Jaarboek Statistiek").

The Table below provides some general guidelines.
(Note: Added Value = total sales value − costs of purchased products)

Economic sector	Economic sub-sector	Added Value in % of sales value
Manufacturing of components	All types of industry	35% – 45%
Wholesale Business- Business	Commodity raw materials Special materials	10% - 15% 20%
Manufacturing, Assembly	All types of industry	30%-35%
Wholesale, End user products	Commodity end-user products Special end-user products	20% 30%
Retail	Big super stores Small retailers	20% - 25% 35% - 45%

Normally you know the value (price) of the end product. In that case, you go backward in
the chain, applying the data of the Table above.

Example: a classical Swiss watch.
- price in the shop (excl. VAT):   200 Euro
- price of the wholesaler(- 45%):   110 Euro
- price of the manufacturer (-30%):   77 Euro
- price of component manufacturer (-35%):   50 Euro
- purchase price of component manufactured (-45%):   27 Euro

Example: domestic appliances.

- price in the shop (excl. VAT):   200 Euro
- price of the importer (-25%):   150 Euro
- price of the manufacturer (-20%):   20 Euro
- price of component manufacturer (-33%):   80 Euro
- purchase price of component manufactured (-45%):   44 Euro

Note: Often many complex chains are "behind" the sourcing of the component manufacturers, so you should stop your analyses of the added value at this point on the chain.

Appendix C: The End of Life stage and Recycling

The way that the EVR model deals with End of Life and Recycling is depicted in Figure 6, and is explained hereafter.
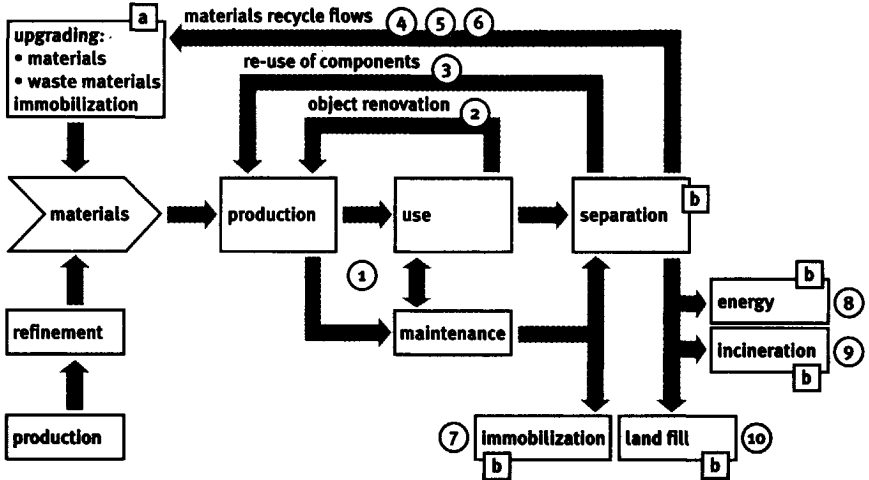

Figure 6: The flow of materials in the Life Cycle

Figure 6 depicts the major types of End of Life treatment and types of recycling. It is developed at the Delft University of Technology to describe and analyse the various kinds of complex modern life cycles of products, buildings, manufacturing plants, civil structures, etc.

The numbers in the Figure relate to the "Delft Order of Preferences", a list of the 10 major systems for End of Life used for structured and systemised analyses of (combinations of) design options:
1. Extending of the product life
2. Object renovation
3. Re-use of components
4. Re-use of materials
5. Useful application of waste materials (compost, granulated stone and concrete, slag, etc.)
6. Immobilization with useful appliances
7. Immobilization without useful appliances

8. Incineration with energy recovery
9. Incineration without energy recovery
10. Land fill

It is important to realise that for big, modular objects (like buildings), there is not "one system for End of Life" but in reality there is always a combination of systems. The way these complex End of Life systems can be analysed within the EVR model is beyond the scope of this publication, but two basic rules for allocation in the EVR model are:
*   Costs and eco-costs of all activities marked with 'b' are allocated to the End of Life stage of a product (transportation included).
*   Costs and eco-costs of all activities in the block marked with 'a' are allocated to the material use of the new product (so are allocated to the beginning of the product chain)[1].

In line with the aforementioned allocation strategy, the 'bonus' to use recycled materials is taken at the beginning of the product chain, where the new product is created. Material depletion is caused here when 'virgin' materials are applied, material depletion is suppressed when recycled materials are applied.
The eco-costs of materials depletion are defined by the costs of the fraction 'virgin' materials, $(1 - \alpha)$, which are used for the new product. In formula:

Eco-costs of materials depletion = (costs of 'virgin' materials) x $(1-\alpha)$

where α is the fraction of used materials for the new product with stems from 'recycled' material (when upgrading is required, *after* the upgrading step).

With regard to eco-costs analyses, two final remarks have to be made within the framework of this manual:
*   One of the consequences of the chosen allocation system is, that all the emissions and energy consumption in the LCA add to the total emissions and energy consumption, however with one exception: incineration with energy recovery (nr. 8). For incineration with energy recovery, there is a surplus of energy, which requires a correction in the LCA for either the eco-costs of energy or the pollution prevention costs for "avoi-

[1] There are many reasons to allocate these activities to the new product. Two major arguments:
*   The processes to use and upgrade recycled materials are often integrated with other processes to make the new product (e.g. recycled paper, recycled steel, etc.)
*   Physical tracing of recycled material flows between the "upgrading step" and the "separation step" is normally not possible (there is generally no direct physical relationship between the old product and the new product)

ded emissions". Note that there is no 'estafette effect' in this allocation system (estafette = relay race).

- For the situation in The Netherlands, the eco-costs of "land fill" has to be set at 100 Euro per 1000 kg, being the costs of prevention of land fill (the main alternative systems for land fill are: making compost of bio waste, incineration of domestic waste in an environmentally acceptable way, recycling building materials.)

The total concept of the "Delft Order of Preferences" and its evaluation method via the EVR model has been published in the International Journal of LCA.

This PhD thesis evaluates the transition towards sustainability *in terms* of the de-linking of the economy and ecology.
This publication is centred around nine research questions:

1. *develop* a single indicator for toxic emissions, the use of *energy*, and materials depletion
2. *develop* an indicator for 'eco-efficiency', being the *Eco-costs / Value Ratio (EVR)*
3. *enhance* the allocation methods in the current LCA methodology to cope with allocation in service systems
4. *incorporate* the End of Life stage of complex products
5. *define* the consequences of the EVR model for design and business strategies
6. *apply* the EVR model on complex service systems
7. *develop* a single indicator for land-use
8. *establish* the hurdles in communication of environmental issues and the EVR model
9. *define* the consequences for companies and governments.

The answers to these questions can help us on the road *towards* sustainability. As such, the EVR model is a new *LCA* based decision support tool for designers, business *managers* and governments.

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