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Environmental Information Systems in Corporate Engineering: Case Studies, Limits and Perspectives

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Abstract

In this contribution two case studies are presented which demonstrate approaches to environmental assessment of industrial products, namely car components. Environmental Information Systems are the tool of choice for the estimation of mass flows within the systems and throughout the entire life cycle.
Environmental Assessment is incomplete if this is the final solution for assessing goods and services for environmental purposes. To achieve corporate engineering it is necessary to use a bundle of methods for an holistic assessment of environmental consequences. Potential further developments of environmental information systems in the process of designing goods and services can be derived from the results of the case studies.

1. Introduction

What are the main forces of strategic and operational environmental management in industry and administration? Primarily these are criteria like economy and safety of goods and services. Environmental aspects of goods and services are mostly viewed in the framework of legislative directives and/or are a question of image or public relations.

An optimisation of production or services in terms of operational or strategic decisions involves integration of economical and ecological criteria. This task faces us with a bundle of problems:

1. System definition: Where is the system boundary? How do we deal with internal and external costs? Do we really talk about "costs"?
2. Data and Information: What kind of environmental data or information has to be derived?
3. Assessment: How can ecological questions be integrated into product planning and safety aspects? What kind of scalar or multidimensional optimisation criteria can be defined?

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All these problems require modern computer science techniques as well as sophisticated and pragmatic solutions in environmental sciences. In this paper two case studies which have to solve the above stated problems are reported and discussed. Each case study is performed in co-operation with different enterprises.

2. Framework: Life Cycle Design

Along with the establishment of environmental objectives at the legislative level prices for goods and services increase due to the fact that environmental costs as well as the effect on other aspects like manufacturing or assembly are taken into account more and more. These costs will be part of the pricing of the manufactures or will be part of the consumer’s buying decision in case they have to pay for the product when it comes to the end of its life.

As a result, companies are increasingly integrating environmental responsibility into their corporate strategy. This requires predictions as to the in-company acceptance of the extended product requirements. Due to the fact that environmental impacts as well as costs are mainly determined at the design stage, approaches are necessary to support designers and responsible persons in the design process.

Life cycle design (LCD) is the systematic consideration of design issues associated with the entire life cycle during the development of products and processes. LCD covers all design disciplines such as Design for Manufacturing (DFM), Design for Assembly (DFA), Design for Service (DFS), Design for Recycling (DFR) and Design for Environment (DFE). These are often referred to collectively as Design for X (DfX), see figure 1. Whereas Design for Environment aims at the minimisation of the environmental impact, the remaining elements of DfX mainly focus on the reduction of costs.

Concurrent engineering is defined by the integration of all elements into a single continuous feedback-driven design process. The main objective of LCD is to support design teams to create products considering the entire product life-cycle from conception through manufacturing and assembly to disassembly, recycling and disposal. Various design approaches and tools are available to support the related design disciplines. However, it has to be considered that this process includes all companies, suppliers or organisations (Hesselbach et al., 2000).

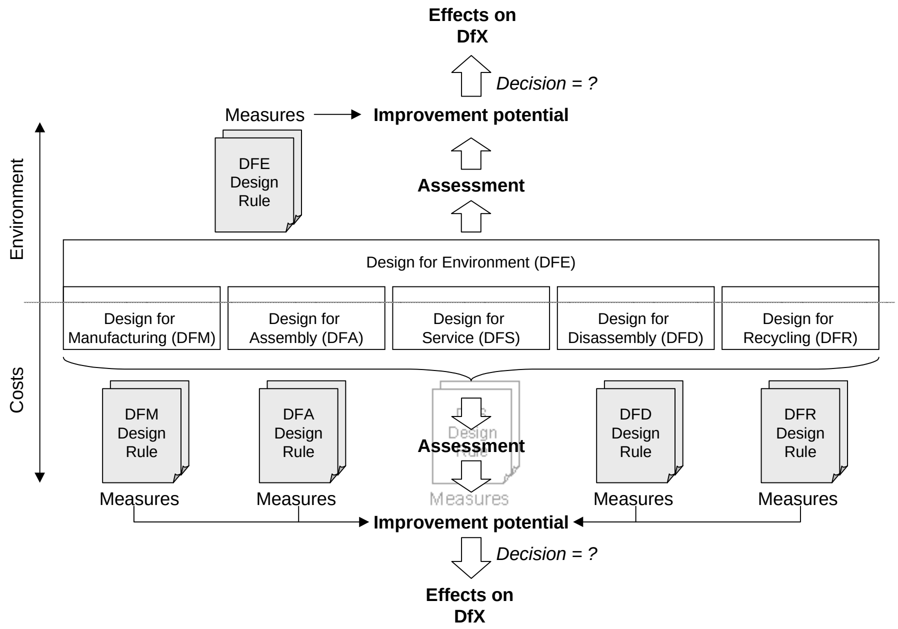

Figure 1
Design disciplines of Life Cycle Development

This state of the art of design of goods and services can be supported by several tools and programs for environmental assessment. Each loop of a design process of concurrent engineering necessitates answers to the question in the introductory section. The following two case studies show how far we get with recent tools of environmental information systems. Hopefully, the report from practice will initiate ideas of what's necessary to fully achieve the aim of concurrent engineering by means of environmental information systems.

3. Case Study 1 – Linking and Integrating Life Cycle Inventory (LCI), Environmental Fate Models and Ecological Impact Assessment using Fuzzy Expert Systems

3.1 Conceptual Framework

Life Cycle Assessment (LCA) is a system-wide assessment, and the Life Cycle Impact Assessment (LCIA) phase is confronted with the difficulties of local and regional effects in a number of impact categories. The following framework of assessment was set up to achieve the desired goal, described in section 2:

In this case study an integration of three different environmental techniques is performed to demonstrate how design goals can be addressed in an environmental assessment. This integration couples (figure 2)

- Life Cycle Inventory (LCI)
- environmental fate modelling, and
- ecological impact assessment using fuzzy expert systems.

Results of the LCI are mass and energy flows. In the environmental fate modelling step, these mass flows are transformed into concentration and discharge values by dispersion-reaction models. A generalised fuzzy expert system for the environmental mechanisms compares calculated exposure with site specific buffering capacities and formulates a generalised dose-response relationship. This generalised fuzzy expert system is used as a template for the assessment of local and regional environmental impacts.

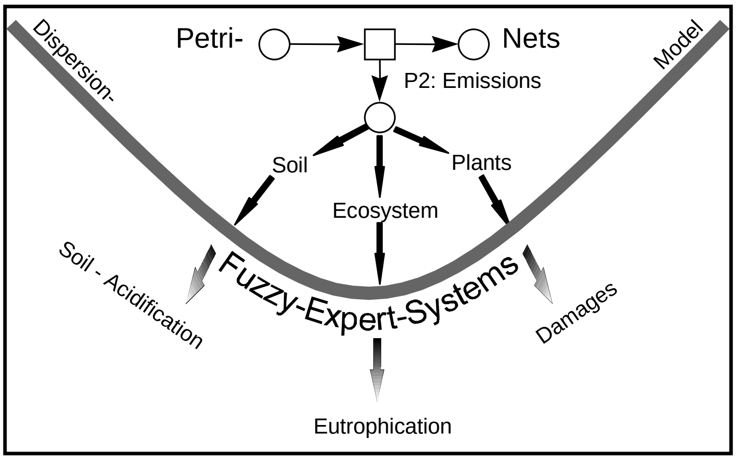

Figure 2
Integrated concept of Life Cycle Assessment

3.2 Application

This concept was applied to the life cycle of car components of the Volkswagen Polo®, produced by Volkswagen AG (Thiel et al. 1999). A Life Cycle Inventory was implemented for the planned production of magnesium door parts using the annual Polo production figures in Wolfsburg for 1995. The environmental fate modelling focused on the fate of emitted nitrogen oxides as they cause several typically regional or local impacts. In the environmental assessment of the NO_x-emissions the possible response of the three receptors crop, soil and ecosystem were assessed.

The following processes were investigated in the LCI for the planned production of the magnesium (Mg) door parts:

- crude Mg production,
- production of the alloy Mg-AM 60,
- smelter,
- die casting,
- part finishing,
- chromate treatment,
- recycling of the production residues (leading to input of secondary Mg-AM 60 in the smelter),
- transportation between the different production sites as well as the recycling facilities.

The Mg production and alloy production take place in Israel. The other processes from smelter to chromate treatment take place in Germany. The data for the production activities were provided by Volkswagen. The transportation processes between the production sites were calculated using databases from the underlying LCI tool Umberto®. The portion of secondary Mg-AM 60 input in the smelter was assumed to be 24.7 %.

The environmental fate of nitrogen oxides which are released due to the major combustion source within that production system are simulated. Fuzzy expert models for crop damage, soil acidification and eutrophication determine the possible environmental impact of the released nitrogen oxides. NO_x-emissions are chosen for detailed study: The results of the LCI show that more than 80 % of the NO_x-emissions are released in the first two processes at the Dead Sea Works in Israel. The remaining NO_x-emissions occur at energy production sites in Germany (16.8%) and in other operations (1.9 %). The high share of NO_x-emissions in Israel is mostly due to the fact that at the Dead Sea Works the energy demand is covered by a power plant burning residual oil. The power plant is located in Israel at the southern end of the *Dead Sea*.

Hence, in the environmental fate modelling we focused on the environment of this site. The emission results of the LCI yield the input flow of the reaction–dispersion model. We made calculations for the annual Mg production of approximately 30,000 t at the Dead Sea Works. The annual demand due to VW Polo production is only about 8.2% of this amount. However, to estimate the potential impact of the NO_x-emissions on the environment near the power plant, the calculations have to be based on the energy demand for the entire annual Mg production at this site.

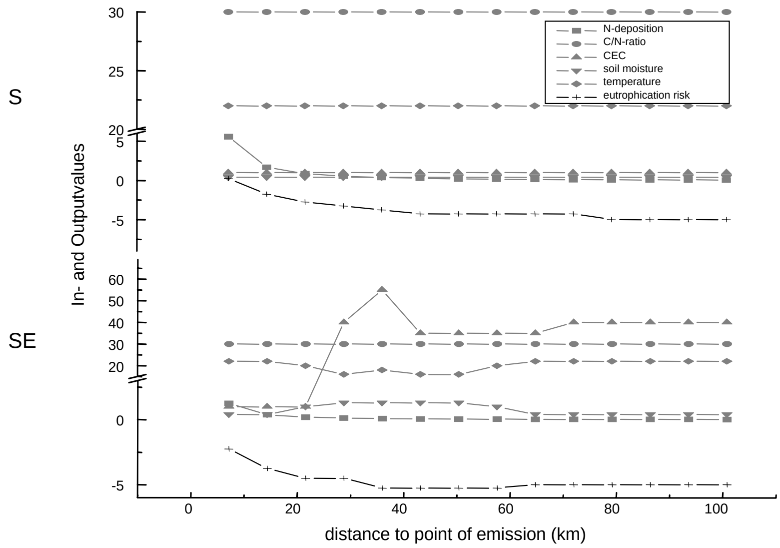

Figure 3
Possible eutrophication impact in the scenario “South” (upper part of figure) and “South-East” (lower part of figure) of the stack. See text for explanation of input and output values.

3.3 Results

The results of possible eutrophication were chosen for detailed analysis. Further analysis focused on soil acidification and plant damage (Thiel et al., 1999).

This is illustrated in figure 3. In the upper part of the figure, the results are shown for the possible impact South of the stack. In the lower part, the assessment results South–East of the stack are indicated. The values for the environmental conditions are taken from Adler et al. (1985). In figure 3 the N deposition is given as total N (in kg/ha a), the C/N ratio and the precipitation/evaporation index are dimensionless, the CEC is given as meq/100 g soil. The unit for the mean ambient temperature near the soil is °C. The possible eutrophication impact is given as kg N/ha a. It represents the difference between N deposition and buffering capacity.

NO- and NO_2-immissions can have adverse effects on the development and physiology of plants (Sanders et al. 1995). However, as nitrogen compounds are also nutrients for plant growth, low doses of NO_x can lead to positive effects on plants (Curtiss/Rabl 1996). Within the fuzzy expert system for possible plant damage three different fuzzy sets have been defined for the susceptibility of plants to NO_x. These sets represent the dose response relationships of the three plant categories very susceptible, susceptible and less susceptible to NO_x-immissions. The possible nutritional effect of low NO_x-immissions has been taken into account within the fuzzy expert system. In the first step of the environmental impact assessment for possible plant damage the different crops in the vicinity of the power plant (up to 250 km distance) are assigned to their respective fuzzy sets of susceptibility and in the second step their response to the NO_x-immissions was estimated (figure 3).

The model for plant effects forecasts a slight increase in potential crop yield South of the power plant. The effects in the other 7 directions for which calculations have been made are negligible.

3.4 Some Answers

The important methodological extension of this integrated approach is the extended system boundary. Analysis and assessment do not end at the chimney or at the factory gate. System definition is extended to the biosphere. Therefore, data retrieval has to be performed not only from the production system, it is extended to environmental and climatic conditions of the surrounding area of the production site. Impact assessment is performed on a regionalised basis depending on the spatial distribution of environmental characteristics, preferably using Geographic Information Systems This avoids a separation between "internal" and "external costs". The results are understood in terms of ecological tolerability.

4. Case Study 2 – Life Cycle Studies on Different Natural Fibre Reinforced Components and Thermoplastics for Automotive Parts

4.1 Aim and Scope

The automotive industry introduced several innovations of environmental performance while the importance of environmental interactions increased. Environmental material selection including renewable raw materials is one example. Products of renewable raw materials, for instance hemp, jute or flax, are generally regarded as environmentally friendly.

The framework of LCA is used to investigate and assess the ecological impact of products like these. However, no general principles of ecological burdens can be deduced from an ecological assessment of fibre plants, since the ecological compatibility of the different products depends on the whole life cycle.

The objective of this study is to provide support for decisions by automotive engineers by giving an ecological assessment of the benefits of substituting thermoplastics by natural fibres for different covering applications (Flake et al., 2000). But how can we support the decision-making process with the objective of identifying fields of impact on the economic and ecological level?

4.2 Methodology and Subject of Investigation

Different scenarios of cultivation and harvesting are modelled and assessed depending on the planned use of fibre plants. For the technology of fibre extraction and fibre processing, the purpose of the product is decisive, and an analysis of the line of production often needs to consider special cases. The life cycle comprises

- agricultural cultivation of fibre plants, which is specific to different regions (global scope),
- methods of harvesting and the post-processing of crops,
- processing of the fibre composite matrix and the production of the different covering applications
- modelling of driving cycles in order to identify the differences in energy demand and emission amount during the use phase of a passenger car,
- set up of scenarios for recycling opportunities or waste disposal.

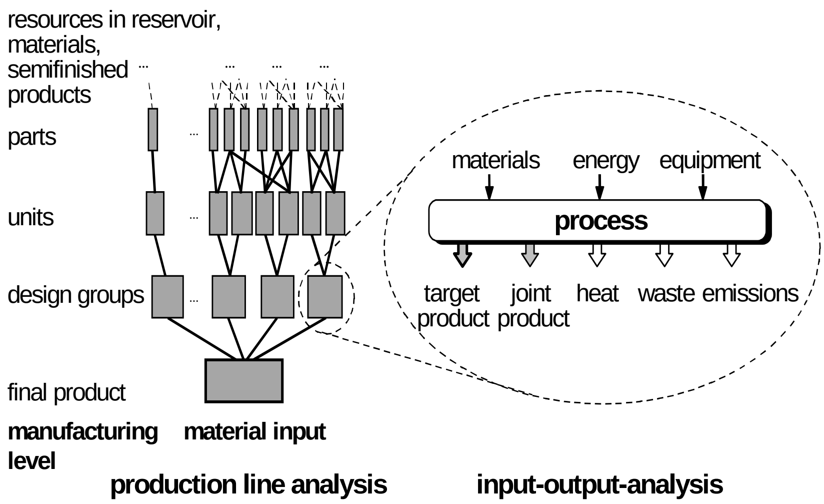

Figure 4
Structure of the Input-Output Analysis

The focus of the study is the quantitative recording of material and energy flows throughout the whole life cycle and their comparison in the sense of a product comparison. The method is illustrated in figure 4: the production chain is divided into individual steps and an input-output analysis of the material and energy flows is carried out for each manufacturing step, taking into account the allocation rules for joint products. The merging of the individual processes into an overall account referring to the functional unit, in this case the functionally equivalent side panel, makes up the quantitative core of an ecological assessment.

The life cycle inventory provides the basis for an ecological assessment. In the ensuing impact assessment the data accumulated in the LCI are aggregated into categories regarding their environmental impact by means of weighting factors according to the standard list of Umweltbundesamt (1995). The environmental impact statement focuses on the demonstration of the cumulative energy demand (CED) and resource consumption, and of global warming potential (GWP) as the result of energy-related emissions and of the potential contribution to acidification and eutrophication, which is especially crucial in the agricultural process chain.

The use of different materials and the resultant weight differences also influence the use phase of a car. The main demand for energy is caused by fuel consumption during the use phase, which represents 80% of the total energy for manufacture, use and disposal of a car (Schweimer/Schuckert, 1996).

Potentials for reducing fuel consumption cover a wide range of values (0.15 – 1.0 litre per 100 kg and 100 km). The quotient for the reduction in consumption is 0.34 – 0.48 litre per 100 kg and 100 km for petrol in the New European Driving Cycle (NEDC) and is lower for diesel-powered vehicles at 0.29 – 0.33 (Eberle/Franze, 1998). Therefore, the reduction in fuel consumption as a result of weight differences in the side panels compared is taken into account in this study for two different engine types. The corresponding fuel economy is calculated in terms of primary sources of energy.

4.3 Results

Figure 5 shows the cumulative energy demand (total of roughly 96 MJ) divided into the life cycle sections for the manufacture of side panels made of a natural fibre and epoxy resin composite. The expenditures for cultivating fibrous plants are clearly reduced due to the division of the fibre gross proceeding into the different production lines and are, for the whole assessment, only of minor importance. The energy assessment is clearly dominated by the epoxy resin-hardener system. The expenditures related to hardware (ABS retainer & hot-melt adhesive based on ethylene) and to natural gas and power consumption during the actual manufacture of the panels are also significant.

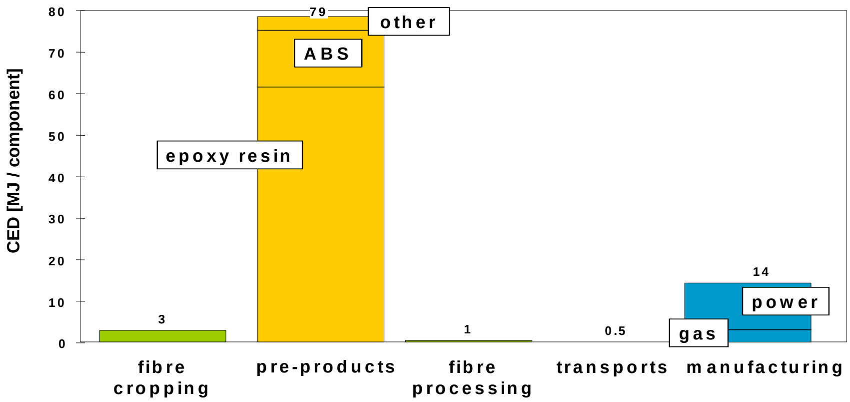

Figure 5
Shares of CED for manufacturing a natural fibre composite side panel

By the time the component is installed, the difference between a natural fibre component and an ABS part as to the CED amounts to roughly 74 MJ in favour of natural fibre components. As for the weight of the different components, there is also a difference of approx. 0.3 kg in favour of the natural fibre support. This lower weight is calculated with the consumption reduction coefficients corresponding to the engine for the use phase of the car.

The energy credit for the natural fibre component is roughly In the same range of 64 – 100 MJ (for a driving distance of 200;000 km) as the difference in the manufacturing expenditures.

The accumulation over the whole life cycle for the CED is shown in figure 6. In this case, incineration is suggested as THE disposal option. The energy credit for the ABS panel, based on the greater calorific value and the higher material input, is approx. 23 MJ greater than for flax-jute epoxy resin panels. Overall, based on the energy analysis, ecological advantages are obtained in a range of 115 – 155 MJ depending on motorization and assuming a driving life of 200,000 km.

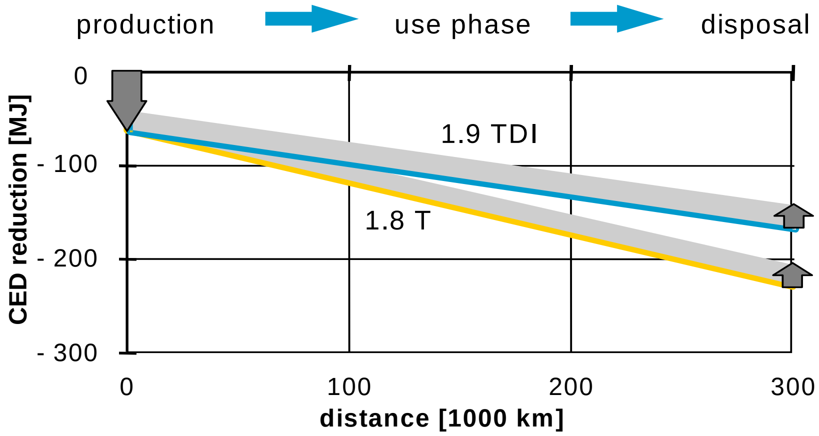

Figure 6
CED reduction for the entire life cycle as compared to the thermoplastic component

4.4 Recycling Loop

The integration of recycling strategies into product planning calls for the definition of new system boundaries within the framework of Life Cycle Assessment. Figure 7 shows the system boundary of the Audi A3 side panel (thermoplastic component): Instead of producing the side panel by a new ABS-injection moulded composite (shown in the upper part of figure 7), recycling loops of thermoplastics are related to a new and more complex production system. The use of regrind thermoplastics (here PC-ABS blends) also influences the cost structure of the production process.

In conclusion, combining the methods of Life Cycle Assessment and Life Cycle Costing is a suitable tool for optimisation of industrial processes. Given the fact that environmental impacts as well as costs are mainly determined at the design stage, approaches are necessary to support designers and decision makers in the design process. These are the new demands on Environmental Information Systems in industrial surroundings.

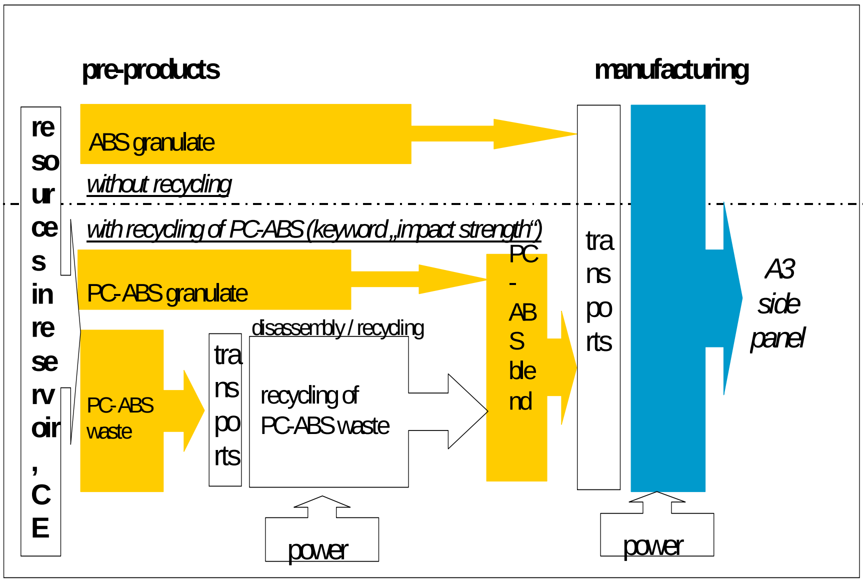

Figure 7
Variation of the system boundary of the A3 side panels
produced as ABS injection-moulded.

5. Answers and Perspectives

These case studies show the limitation of LCA software-tools. The tools offer a database and a connection to common environmental indicators. A combination of different methodologies was necessary to accomplish the tasks posed by the case studies. In case study 1 environmental fate modelling linked results from LCI to environmental impact analysis. In case study 2 different indicators and scenario techniques were used to assess the entire life cycle.

Second, all case studies point out that LCA studies and their described extensions necessarily involved the use of vague data. Interpretation and assessment of results is therefore performed verbally and by argument according to a hierarchical model, as shown by case study 2. This requires intensive co-operation between environmental scientists and the stakeholders.

Case study 1 shows that environmental impact assessment needs a site-dependent interpretation. Geographic Information Systems (GIS) are used here for integration of LCI results, emission values, environmental fate modelling and site dependent assessment. The use of GIS offers more opportunities for impact assessment as well as system definition. Pure LCA methodology remains insufficient when it is limited to static analysis without the integration of environmental fate (case study 1).

The current state of computer sciences offers methodologies and technologies for maintenance and analysis of huge amounts of heterogeneous data and information. However, pure computer science is not sufficient when specific applications in environmental sciences have to be assessed. This is an interdisciplinary task. It has to be performed in co-operation with environmental scientists.

Practical problems define 'their' viewpoint of the environment. This is the reason for the current wide spectrum of techniques and methods in environmental information systems. The case studies demonstrate this spectrum. Up to now, 'environment' is only understood in the framework of a specific problem or purpose. For a more general methodology and technology of environmental information systems, this ontology has to be developed. A fascinating and challenging enterprise.

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