“Oil Points” -
Designers’ Means to Evaluate Sustainability of Concepts

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Abstract

Designers have an essential influence on product design and are therefore one target group for environmental evaluation methods. This implies, that such evaluation methods have to meet designers requirements. Evaluation of sustainability of products is often done using formal Life Cycle Assessment (LCA) methods. The different LCA based methodologies consider different environmental exchanges and are often rather complex.

In this context, the authors raise the question, whether a simplified LCA method which is only based on energy considerations can be used as a tool for quick overviews. This is investigated by means of three case studies where environmental impact is estimated using the EDIP method, the Eco-indicator 95 method, and the Oil Point method proposed by the authors. It is found that the results obtained using Oil Points are in acceptable conformity with the results obtained with more complex methods. This, however, is only valid as long as chemical substances can be neglected in the considered life cycle systems. Comments from workshops with designers, where the cases were presented, are included in the paper.

Keywords

Product Development, Design for Environment, Sustainability, Life Cycle Engineering

1 Introduction

1.1 Sustainability and Environmental Aspects in the context of this paper

There is a broad consensus over the fact that our way of living has to become more sustainable in order to preserve today’s scope of abilities for coming generations. In this context, sustainability has to be seen in an environmental, economical and social/societal perspective. The environmental perspective shall be the focus of this paper.

A large portion of human influence on the natural environment is based on industrial activity. The subject of this industrial activity are products. While the environmental focus in industry and in legislation first was on the production processes used to produce these products, a shift took place in the beginning of this decade from the production processes to the products themselves in their life cycle.

This is due to the fact that minimising environmental effects in one phase of the life cycle may increase pollution in another, [ALTING, 1995]. The aim, however, must be to minimise the *overall* environmental consequences of our "product consumption" as such. Establishing a sustainable industrial production is the only way to handle the future challenge which is to produce more products with less natural resources and lower environmental load per product, see [ALTING ET AL., 1996].

1.2 Integration in Product Development

Based on the life cycle approach, tools and methods for analysis and assessment of products have been developed. A common term for this is LCA - Life Cycle Assessment. Such tools for environmental assessment have to be integrated into the product development process in order to be most effective. The integration can focus on the strategic and/or on the operational level. While an integration on the strategic level is mainly management oriented, the integration on the operational level is aimed at the individual product developer, engineering designer or industrial designer. This group of persons is the target group in this paper and is referred to under the common term *designer*.

When selecting materials and manufacturing processes, designers have a substantial influence on the environmental characteristics of the product in its whole life cycle. This is, because a material which is easy to process and cheap in purchase may for example be accompanied by a considerable depletion of natural resources for its production. It may as well result in significant environmental impacts when disposed of. The life cycle concept and the designer's important role in it are two core considerations in putting "Sustainable Industrial Production" into practice, see [ALTING, 1995].

Many environmentally important characteristics of a product, e.g. the materials, are defined at a level of product design where the product is just represented as a concept study, e.g. as a sketch. At this operational level there is use for rough methods, where results can be obtained after a relatively short period of time, see [ANDREASEN ET AL. 1996]. Formal Life Cycle Assessment, however, is a comprehensive, very data intensive and thus time consuming tool because a lot of information about environmental contexts and consequences have to be treated. Furthermore, especially industrial designers work very intuitively, unstructured, and their background in environmental evaluation is often very limited, see [BAKKER, 1995].

1.3 Aim and idea of the research

The overall aim of the research is to identify, which environmental information designers need - and how little is necessary (in terms of a top-down approach)- in order to evaluate product concepts on the basis of materials and manufacturing processes involved.

A basic fact in LCA is that the major part of environmental impacts of a product origins from the areas chemicals and energy. The only relevant contribution from a product's secondary life cycle (i.e. production of machines to manufacture products, etc.) is its energy production. In the case of energy consuming products, this consumption of energy is typically responsible for the lion's share of all potential environmental impacts, see e.g. [EDIP, 1997], p. 389. Considering these circumstances, the basic hypothesis for the research presented in this paper is that a rough - but nevertheless quantitatively correct - evaluation of products with their different materials and manufacturing processes can be done by exclusively comparing related energy consumptions.

For this purpose three case studies are being conducted, referring to three different classes of products:

- passive products, i.e. products which do not consume energy during the use phase are represented by ***a window frame***,
- active products, i.e. products which directly consume energy during the use phase are represented by ***a coffee machine***, and
- textile products which indirectly consume energy during the use phase are represented by ***a sweater***.

In these case studies, different product solution principles are compared using three different environmental evaluation methods. The hope is to justify that a fairly simple method qualifies as sufficient estimation for the overall environmental characterisation of engineering materials and manufacturing processes, thus allowing environmentally untrained persons to give rough estimates of environmental consequences.

2 Methodologies for Environmental Evaluation

2.1 Environmental Evaluation

When trying to make evaluations in an environmental context, a holistic contemplation of life cycle systems is important. A well-established means for such holistic life cycle considerations is Life Cycle Assessment, LCA. Efforts to reach international standards are in progress but not finished yet. However, basic elements are agreed upon.

In LCA, generally four life cycle phases are distinguished. These are:

1. Raw Material Extraction/ Material Production,
2. Manufacturing,
3. Usage and
4. Disposal

Transport processes between the phases are either distributed under these phases or summarised in a separated fifth phase.

An LCA consists of four steps:

1. Goal Definition, 2. Scope Definition, 3. Inventory, and 4. Impact Assessment

The Impact Assessment step can be subdivided into

4a. Classification, 4b. Normalisation, and 4c. Weighting.

In steps 1 (Goal Definition) and 2 (Scope Definition), the aim of the LCA and its frame - i.e. the considered life cycle and its borders - are defined. In the Inventory (step 3), a complete balance of all inputs and outputs of all processes in the life cycle is done. In the final Impact Assessment, (in- and) outputs can be classified as belonging to certain categories of environmental problems, they can then be normalised - in order to have a common measure - and then weighted, in order to mirror the relative importance of a category. An example for this in the context of the EDIP methodology is given below.

Due to, for instance, the differences in products but also in the aim of an LCA, there are today several life cycle based assessment methodologies considering different classes of impacts (4a), different normalisation units (4b), and/or different weighting principles and weighting factors (4c). The Impact Assessment step is a controversial element of LCA standardisations.

LCA methodologies can also focus on different exchanges with the environment: Besides potential environmental impacts, they can also take resource consumptions or even potential impacts on the working environment into account.

With respect to, for instance, the number of LCA steps actually considered, LCA projects can be termed with the prefix “full-” or “simplified/ screening-”.

In the case studies presented in this paper, three different environmental evaluation methods, namely **EDIP** [EDIP, 1997], **Eco-indicator 95** [PRE, 1995] and the simple **Oil Point method** are utilised. These methods can be seen as representing a full LCA, a simplified LCA and a simplified LCA which is only based on energy balancing, respectively. In the following section, the utilised methodologies are described and summarised briefly. Some of the points made in the summaries are comments from the workshops.

2.2 The EDIP methodology and general LCA steps

This methodology was developed in the scope of the EDIP project (*E*nvironmental *D*esign of *I*ndustrial *P*roducts), [EDIP, 1997; WENZEL ET AL., 1996; OLESEN ET AL., 1996]. The project involved several institutions related to The Technical University of Denmark, the Danish Ministry for Environment and Energy and a couple of Danish companies.

The methodology is the most comprehensive one of all the ones used in this case study. It is the only one also taking resource depletion and effects on working climate into account. Impacts can be traced all the way back to their origins. Due to this comprehensiveness, however, the results - generally given as bar charts - are complex as well.

Estimations for missing data are - even for specialists - virtually impossible. Comparing results of different material or process selections is rather difficult as well. This method is therefore not too appropriate to be used by designers who do not have specific knowledge in environmental assessment.

The full LCAs of the case studies were performed according to this methodology using the accompanying computer tool (version 2.06 beta). Besides Goal & Scope Definition, the EDIP methodology comprises the steps Inventory and Impact Assessment, the latter including a Characterisation, Normalisation, and Weighting. A couple of these expressions shall be described in short:

Goal & Scope Definition
Any product LCA has a meaning. For instance, a producer may wish to document how his product performs compared to the one of a competitor. He has to decide whether he wants his own staff to perform the LCA or e.g. a consultancy. The scope of the LCA may comprise only a few main elements of the life cycle of the product in question or a lot of secondary systems and elements. The results may for instance be used for advertising, for internal tasks or in order to comply with certain regulations. Issues like these often turn out to be very important in later phases of an LCA and thus have to be clarified in the first two steps of an LCA.

Inventory
From all building blocks - or phases - in the life cycle, an input/output balance is made in the Inventory step. While the inputs can be traced back to resource consumptions, the outputs can lead to impacts on the natural environment and on the working environment. Due to the fact, however, that the exact behaviour of the outputs in the environment is rarely known, the common expression used is *potential impacts* respectively *impact potentials*. In the present case study, we are only looking at potential impacts on the natural environment. Therefore, the *Inventory* of the present LCA focuses on outputs.

Characterisation
In the subsequent *Characterisation*, these outputs are then translated into contributions to environmental impact categories like ozone depletion (resulting in “ozone holes”), global warming (“greenhouse effect”), landfill, etc. A total of 18 such environmental impact categories are treated in the EDIP methodology.

Normalisation
Those contributions are not directly comparable: It is difficult to determine whether or not 3 kg CO_2 output are more harmful than 1 g radioactive waste. All contributions to impact categories are therefore *normalised* to so-called person equivalents (PE). A PE is one person’s average "share" of the global annual output of the matter in question.

To give an example, the normalisation unit for “Global Warming” is for instance “8,700 kg CO_2-equivalents per person and year”. For “radioactive waste”, the unit is “0.035 kg radioactive waste per person and year”. The normalisation makes it possible to describe the 3 kg CO_2 output as 0.000,345 PE and the 1 g radioactive waste as 0.028,571 PE.

Typical values of person equivalents are smaller than 1, thus the typical unit utilised in LCA is milli-person equivalents, mPE. In the little example, the3 kg of CO_2, being 0.345 mPE, are thus - at this stage of the assessment - quantitatively a by far less important contribution than the 1 g radioactive waste, which correspond to 28.571 mPE.

Weighting
In a final *Weighting* step, the “relative seriousness” of the impact categories is mirrored. The mPEs are therefore multiplied by specific weighting factors. Those weighting factors in turn are - in the EDIP method - defined on the basis of for example global and Danish reduction targets for the year 2000.

The unit for weighted data is thus called “Target Person-Equivalents, PET”, where T stands for “target” (PETs are also typically expressed as milli-PETs, mPET). The more serious and the farther away from the target value an impact category generally is, the higher the weighting factor.

The weighting factors for CO_2 and radioactive waste are 1.3 and 1.1, respectively (Remark: For ozone depletion it is 23 !). The weighted result is thus, that 3 kg CO_2 are equal to 0.449 mPET, while the 1 g radioactive waste equals 31.428 mPET, which is extremely higher. The described procedure of Impact Assessment, i.e. of transforming Inventory Data to Weighted Data is shown in **figure 1**.

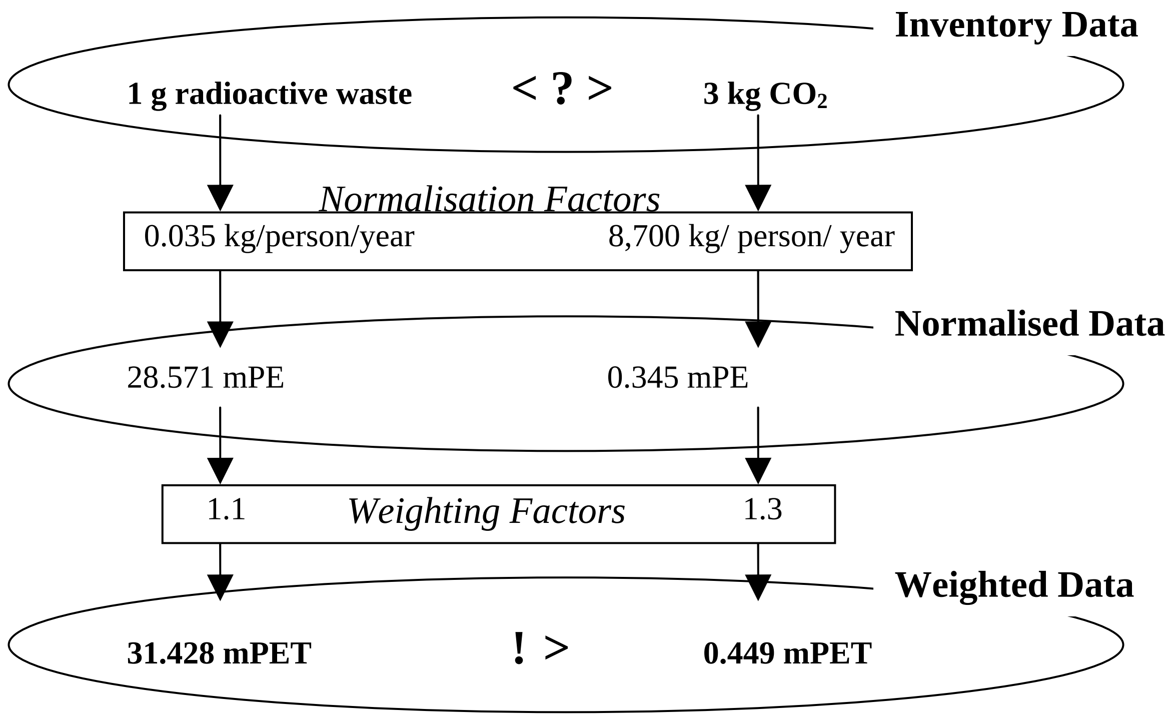


Figure 1: Transformation of non-comparable Inventory Data to comparable Weighted Data during Impact Assessment according to EDIP

<u>Summary of the EDIP methodology:</u>

- Represents a methodology that enables Full-LCAs
- \+ Takes resource consumption, environmental impacts and working environment into account (*In the present paper, however, only environmental impacts are considered!*)
- \- Manufacturing processes and materials are not directly comparable
- \- Missing data cannot be estimated
- \+ High impacts can be traced back to their origin

2.3 The Eco-indicator 95 methodology

A methodology developed in The Netherlands by Philips and the consultancy PRé is the "Eco-indicator 95", [PRE, 1995]. The method is easy to learn and has a single value as a result: a milli-point figure. Milli-points (which are comparable to the milli-person equivalents of the EDIP methodology) can be summed-up over all life cycle phases, resulting in one single score.

A milli-point figure is calculated by multiplying a certain amount of material by a specific *Eco-indicator*. Eco-indicators are based on Life Cycle Assessments. ABS (plastic) granulate, for instance, has an Eco-indicator of 9.3 milli-points per kg. The utilisation of 2 kg ABS would therefore result in 18.6 milli-points. Its processing, e.g. injection moulding, has an Eco-indicator of 0.53/kg resulting in 1.06 milli-points.

For each material and process in the life cycle, such simple calculations are performed. The result of a material and process utilisation can be compared to results of alternative choices. However, the origin of a high Eco-indicator can not be traced back, making this methodology not as suitable for optimisation tasks in product development as the EDIP method. The tenable estimation of missing Eco-indicators cannot be done either, without at least having comparable indicators as basis.

EDIP and Eco-indicator also differ in the number of environmental problems taken into account. The LCAs the Eco-indicators base on do, for example, not consider raw material depletion or toxic substances. The former problem is not taken into account due to the problem of defining depletion, the latter due to the fact that toxicity is considered to only be a problem in local areas, e.g. at certain workplaces.

<u>Summary of the Eco-indicator 95 methodology:</u>

- Represents a simplified LCA methodology that enables e.g. Screening-LCAs
- \- Takes only environmental impacts into account, but no toxic substances
- \+ Manufacturing processes and materials are directly comparable by means of the Eco-indicators
- \- Missing Eco-indicators cannot be estimated by non-specialists without comparable ones
- \- Origins of high Eco-indicators cannot be traced

The methodology comprises all LCA steps, namely Inventory, Classification, Normalisation and Weighting. The underlying normalisation and weighting principles are different from the ones used in the EDIP methodology.

2.4 Oil Point method

The energy-based evaluation was done under utilisation of data for energy consumption and energy contents. This evaluation method is based on the basic LCA recognition mentioned before (saying that the majority of environmental impacts origins from energy consumptions and chemicals of the product's primary life cycle (compare e.g. [EDIP, 1997], 135 ff.) and in the related secondary energy production) and on the hypothesis that a rough estimate of environmental consequences can already be determined by calculating energy balances in all life cycle phases.

For the case studies, the authors used a simple self-defined energy balance method - the Oil Point method. Its calculation and scoring principle is comparable to the Eco-indicator 95 method, therefore it could also be called *Oil (Point) Indicator method*. However, materials and processes are here described only by equivalents in oil consumption.

1 Oil Point (OP) equals **1 kg of oil** which in turn equals **45 MJ**.
An Oil Point indicator is a number of Oil Points per amount, e.g. 3 OP/kg.

1 kg ABS plastic granulate, for instance, requires about 1 kg of oil for the material and another one for its processing to granulate. The Oil Point indicator is thus 2 OP/kg. The heating value of oil is about 45 MJ/kg, thus 1 OP is also equal to 45 MJ. If processing this material by injection moulding would require 10 kWh electricity per kg, this would result in about 2.5 OPs. This is because - including efficiency factors - 1 kWh equals about 10 MJ which in turn equal about 0.25 kg oil, i.e.0.25 OPs.

Similar to the Eco-indicator, results can be summed-up for each phase and finally for the whole life cycle. Other than with the Eco-indicator method, however, missing Oil Point indicators can quite easily be estimated.

It shall be stressed at this place, that this method neither is a formal LCA method nor is well-established as such. Its utilisation is also very much based on simplifications and estimations. The method seems, however, to be a very vivid and thus easy comprehensible way to facilitate rough evaluations of environmental behaviour of products.

Summary of the Oil Point method:

- Does not represent a formal LCA method
- \- Takes no environmental exchanges into account
- \+ Manufacturing processes and materials are directly comparable by means of Oil Point indicators
- \+ Missing Oil Point indicators can be estimated by non-specialists
- \+ Origins of high Oil Point results and high indicators can easily be traced back

In the following section, the three methods are utilised for evaluating example products for three different product groups.

3 Three Case Studies of Environmental Evaluation in Materials Selection

In order to examine the methods, it was decided to examine three products belonging to environmentally relevant groups. Possibilities to subdivide products with respect to their environmental behaviour are for instance their *life time* (e.g. short, medium-ranged, or long), a figure which indicates *how long* a product affects the environment. Another possibility for subdivision is the *production volume* which gives an impression of *how intensive* the environment is affected by a product series.

With respect to the thesis of this paper, namely that energy-related evaluations may qualify as an appropriate means for designers, “active” products, “passive” products, and textiles were chosen to be examined. Active products consume energy during their use whereas passive products don’t. Textiles indirectly consume energy during their use phase because they are being washed and dried. Textiles may thus be called “indirectly active” products. In the case studies, these different groups of products are represented by window frames, a coffee machine and sweaters, respectively.

The example products were evaluated by means of all three methods described in the previous section. Results were afterwards presented to designers and product developers. The case studies had two reasons: on the one hand correlations between results of different evaluation methods should be investigated. Such correlations could for instance be similarities with respect to the main result, i.e. for instance that the same critical phases in the life cycle of a product would be detected by all methods or that in a comparison of different materials a certain one would perform best in all methods. On the other hand, the applicability of the different evaluation methods should be argued and discussed in order to investigate requirements of designers.

All case studies were performed after a common structure. It consists of a description of the product, its life cycle (all evaluations base on the same respective life cycle), three evaluations, and a summarised result with brief conclusions. This structure is described in detail by means of the first case study. The subsequent descriptions of case studies, are confined to case-specific key information.

In addition to the brief conclusions at the end of each case study, the aspect of general correlations will be subject to a final conclusion at the end of this paper.

3.1 Case 1: Two window frames - as example for passive products

In this first case study, materials used in passive products were examined. Window frames manufactured in plastic and in wood, respectively, were chosen as example product. Both frames have the size of 118 cm x 118 cm. For reasons of simplification, they are defined as non-openable because all elements of an opening mechanism are assumed to be the same for both frames and thus imply the same environmental impacts. The glass pane as well as all cleaning processes are not included either due to the same reason.

The plastic frame consists of roughly 7 kg plastic (mainly PVC) and about 6 kg electroplated steel profile. The wooden frame mainly consists of about 9 kg wood.

A life time of 40 years for the window frames was assumed. Use and disposal should take place in Denmark and land filling was determined as realistic disposal scenario.
The different life cycles of the two window frames were modelled on the basis of literature information and personal conversations with manufacturers and authorities. On the basis of a subsequent inventory of inputs and outputs, the frames were then evaluated by means of the three different assessment methods.

The following sub-sections thus contain a description of the two life cycles, comparisons of the corresponding EDIP, Eco-indicator 95 and Oil Point, i.e. energy-based evaluations and a final conclusion on the window case.

3.1.1 The two life cycles and Inventories

In this section, the life cycles of two window frames are described. The life cycle of the plastic frame is depicted as block diagram in **figure 2**.

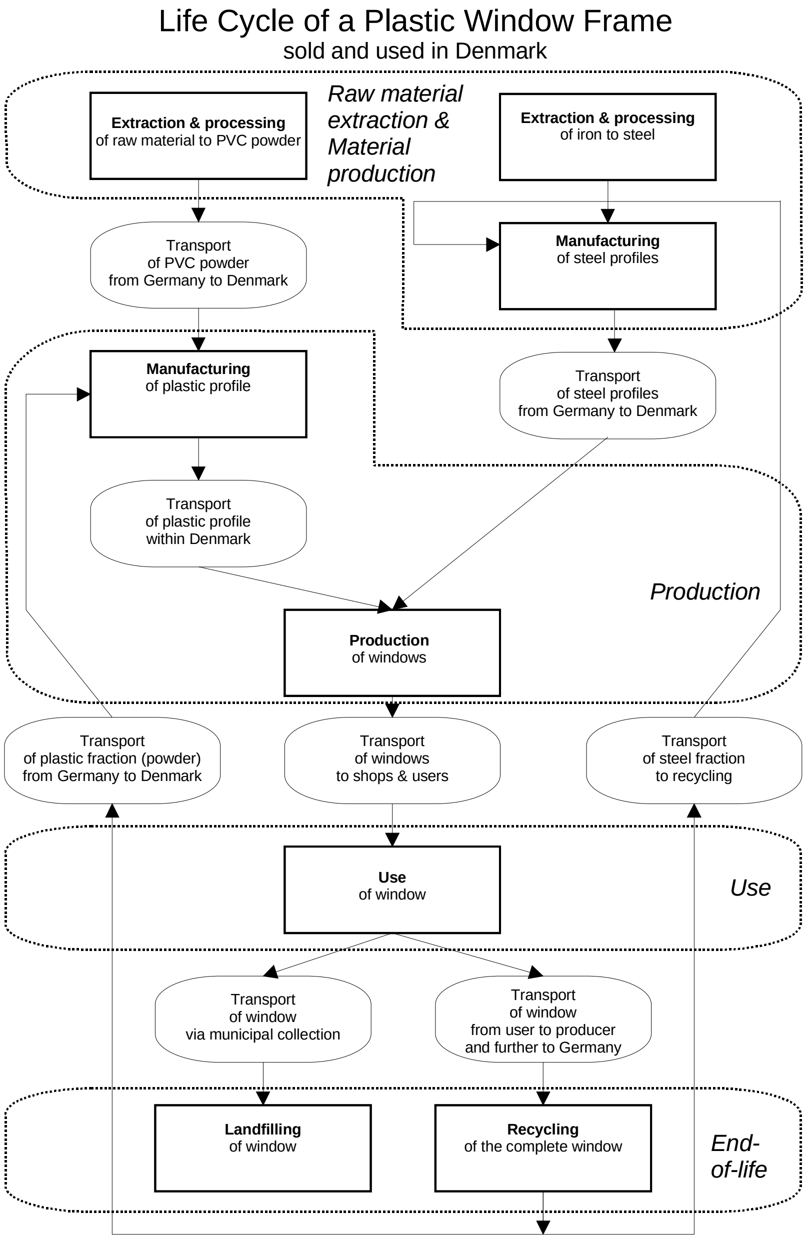


Figure 2: Life cycle of a plastic window frame sold and used in Denmark

Some building blocks are grouped together in the four phases Raw Material Extraction & Material Production, Manufacturing, Use and Disposal. The sum of all transport processes represents a fifth phase.

The model comprises two routs of material production: one for the plastic body - consisting of about 7 kg mainly PVC - and the other for the steel profile - consisting of good 6 kg galvanised steel - used to reinforce the window frame. Both routes meet in the production of the actual window.

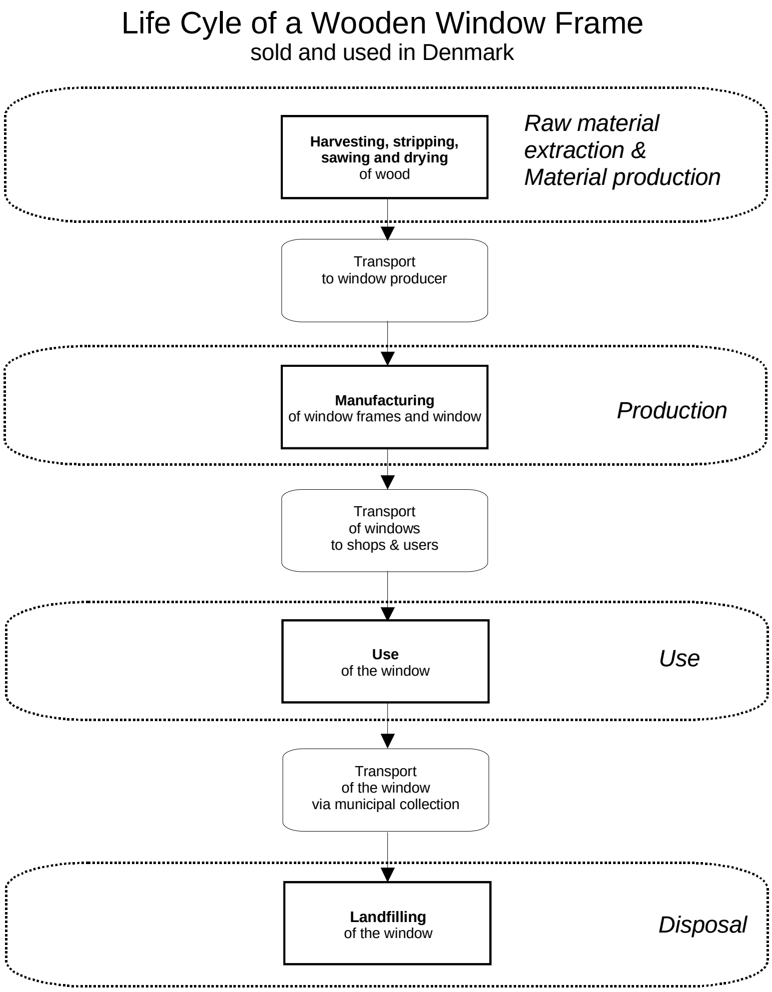
In the use phase - which is defined to last 40 years - the plastic frame is not treated at all apart from the negligible occasional washing combined with cleaning the window pane.

There are two possible end-of-life scenarios for the plastic frame: The by far largest number of frames in Denmark is disposed of by municipal collection and subsequent landfilling. Alternatively, it is possible for the producer to collect the frames and send them to recycling to Germany where a system for recycling of PVC-frames is emerging [FREI, 1996].

The recycling scenario, however, is not taken into account here because only less than 1% of all frames in Denmark are treated in this way [VSO, 1997].

Generally, the transport processes in all described life cycles are calculated as a separated phase in order to mirror possible influences of long-distance transports. Concerning these transport data, it is interesting that most processes of the plastic frame's life cycle happen in Denmark and Germany, while respective countries for the wooden frame are Finland and Denmark.

A model of the life cycle of the wooden frame is given in **figure 3** below.



The material production for the wooden frame, i.e. harvesting, sawing, drying, etc. of lumber, takes place in Finland.

Via train and ship, the lumber is then transported to Denmark where pressure water-proof wooden frames and subsequently whole painted windows are produced.

The windows are either transported to shops or directly to the user. The difference, however, is not significant.

During use, the windows are painted every fifth year in the life time of 40 years, summing-up to a total of nine times painting.

Figure 3: The life cycle of the wooden frame sold and used in Denmark

Due to chemicals involved in the pressure impregnation, also wooden frames are disposed of by landfilling.

Summary of the models:
- Life time 40 years
- Plastic: production from primary material, no treatment during use, disposal via landfilling
- Wood: use of core wood, pressure impregnation, painting every fifth year, disposal via landfilling

Inventory

Parallel to building-up the life cycles, data on inputs and outputs of each building block were collected. As a second step in the evaluation, these data are now added. The amount of information gathered in such an Inventory is relatively high. In order to give an impression of this most comprehensive and time consuming element of any environmental evaluation, an excerpt of the data for the plastic frame is depicted in **figure 4**.

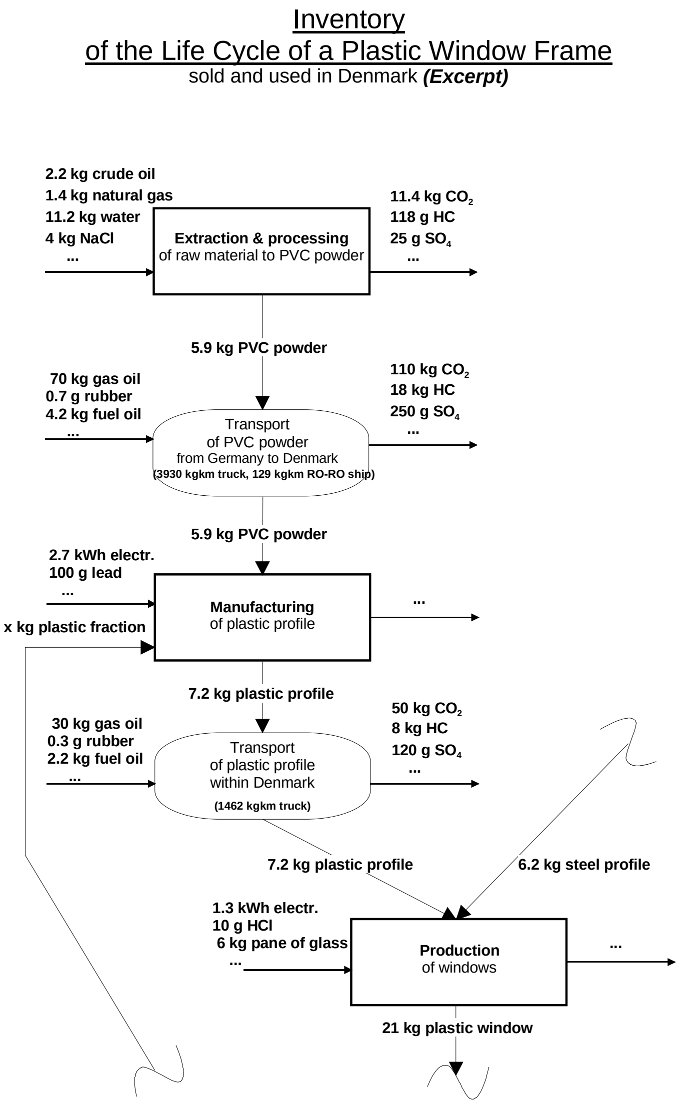


Figure 4
(on the left):
Excerpt of the Inventory for a plastic window frame

Data sources were mainly manufacturers, particular business organisations, the EDIP process data base, and individual persons. Such an Inventory was made for each product.

It shall be mentioned here that the quality of any Inventory is highly dependent on the quality of the data sources used: Usage of many assumptions and average data - which usually has to be done due to lack of exact data - makes the resulting Inventory to a less precise recording of the real processes.

In the next step in the case studies, the products were evaluated with basis on the Inventory data. All evaluations were based on the same respective life cycle and Inventory. For the EDIP evaluation, the accompanying simulation-tool - also called EDIP-tool or LCV-tool - (version 2.06 beta) was used to model the life cycle and to make an Impact Assessment.

3.1.2 The *EDIP* models and evaluation results

The model of the plastic frame's life cycle - designed with the EDIP-tool - is shown below (**fig. 5**). In this computer tool, the life cycle of the product is modelled in a way which is comparable to standard Windows[TM] file management utilities. The product folder contains folders for the life cycle phases.

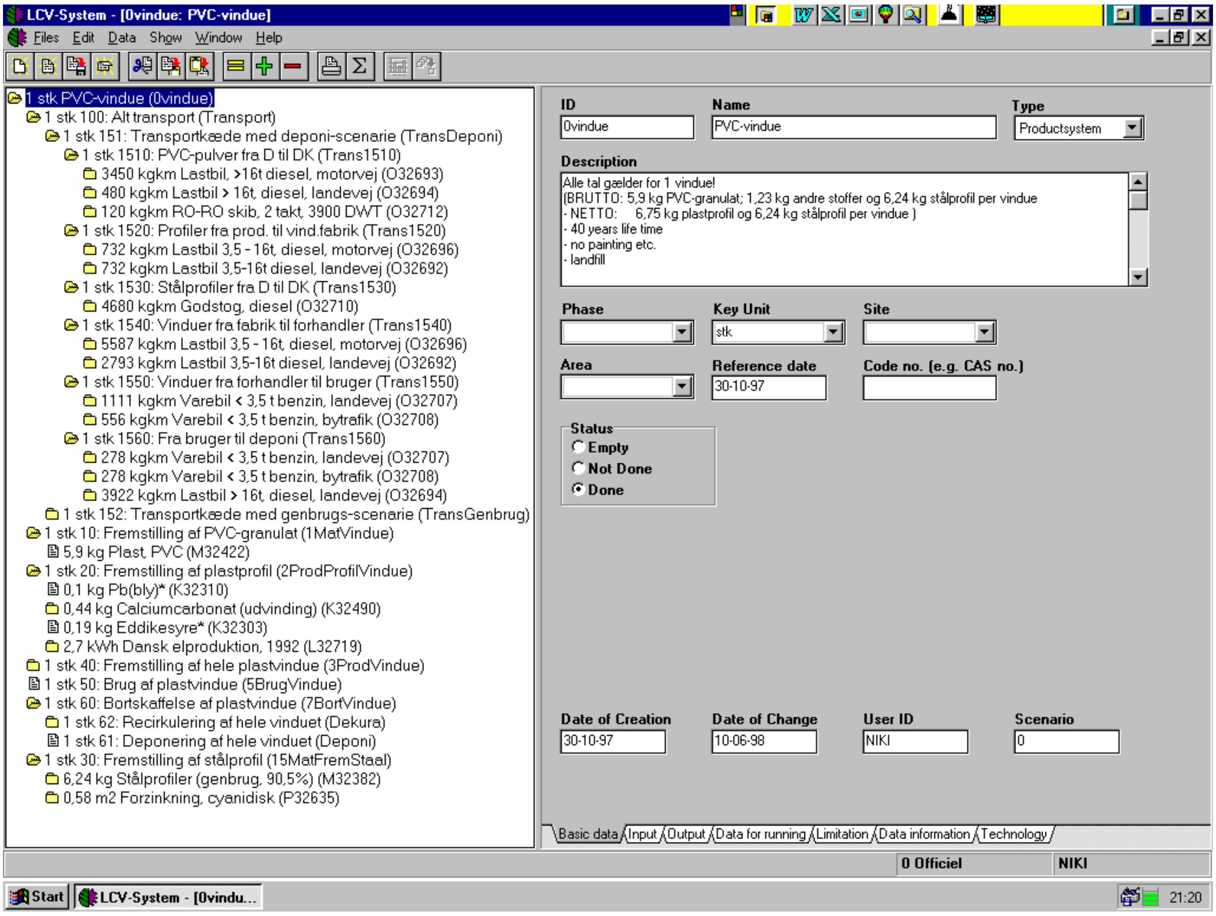


Figure 5: The life cycle of the plastic frame designed with the EDIP-tool (model with Danish text)

Each phase folder - i.e. the folder of “Material Production”, “Manufacturing”, “Use”, “Disposal” and “All transport” - in turn contains folders for the different building blocks of the respective life cycle phase. The actual input/output data are placed inside these building block folders. For example, the manufacturing of the plastic profile (in Danish: *fremstilling af plastprofil*) from 5.9 kg PVC-granulate requires - among other things - 2.7 kWh (Danish) electricity as input (see also figure 5 again). Danish electricity is a pre-defined process which again involves inputs and outputs. About 350 such processes are pre-defined in the present version of the LCV-tool.

For the calculations in the EDIP-tool, the sequence of phases in the model is not relevant. Due to this circumstance, the models in figure 5 and 6 are acceptable although the sequence of phases may not represent the real one. The important thing is not the sequence but the contents of the phase folders.

The LCV model of the life cycle of the wooden frame is depicted in **figure 6** below.

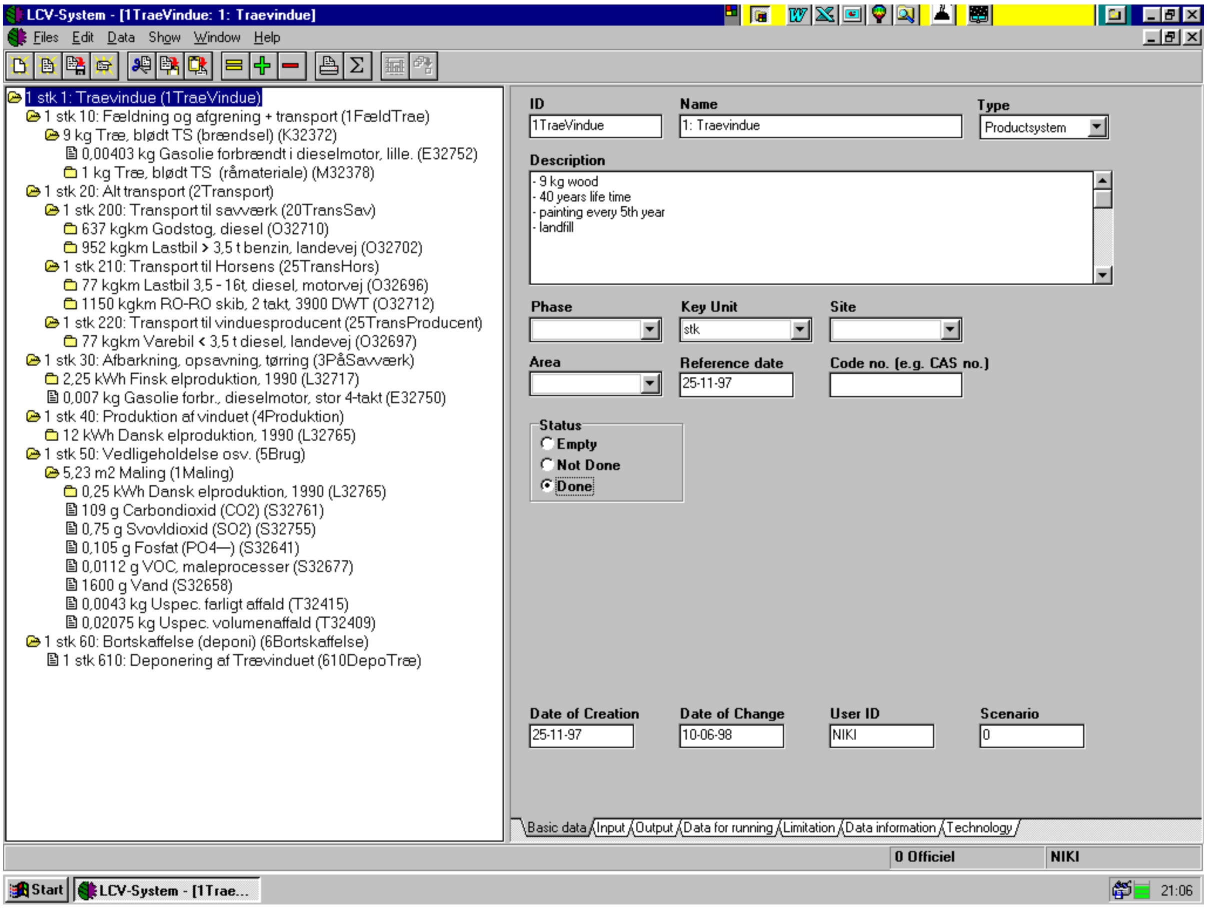


Figure 6: The life cycle of the wooden frame designed with the EDIP-tool (model with Danish text)

Both EDIP models were used for environmental Impact Assessments. This means that the Inventory data were *characterised*, *normalised* and finally *weighted*. All these steps were done by the EDIP-tool.

It shall be stressed here that in the presented case studies exclusively potential impacts on the *natural environment* were considered. The reason for this is that aspects of resource depletion and working environment - which are considered in the EDIP methodology and thus are automatically calculated as well - are *not* considered in the other two evaluation methods utilised in the case studies.

Results of Impact Assessments, i.e. values for weighted environmental impact potentials, are usually given as a *bar chart* of contributions to environmental impact categories. Such a typical bar chart is shown below (**fig. 7**). Each contribution is expressed in **t**arget **m**illi-**p**erson **e**quivalents, mPET.

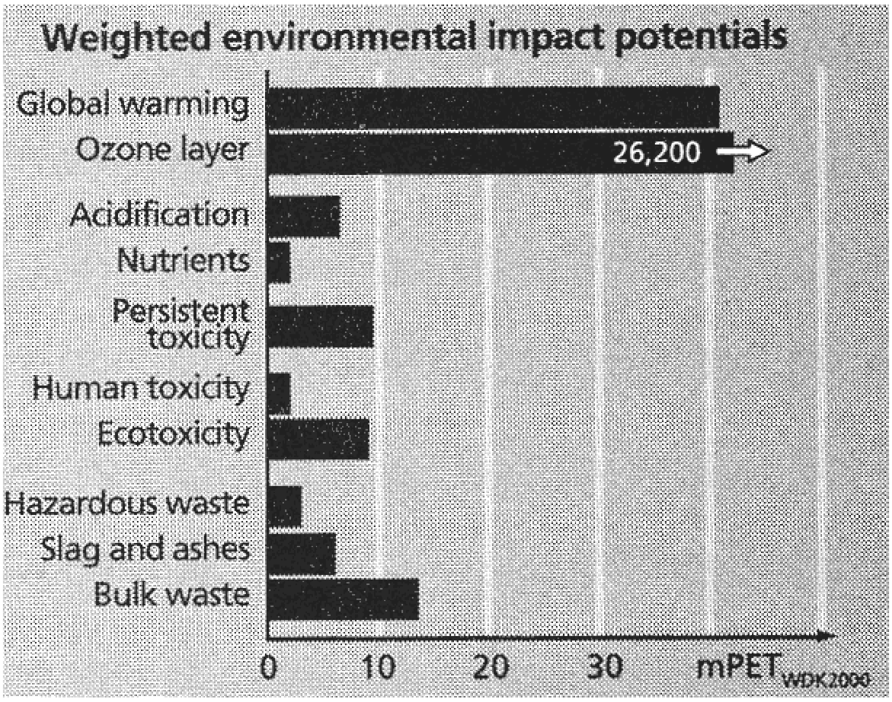


Figure 7: A typical EDIP bar chart result [EDIP, 1997]

Characterising, Normalising, and subsequent Weighting of the Inventory data resulted in a set of mPET values for 15 environmental impact categories. These amounts of mPETs were then summarised for each phase. In order to get one single value and thus make results of the EDIP methodology better comparable to the other methods, the resulting milli-person equivalents of all phases were finally summed-up again (Both summarisations - for the single phases and the total life cycle, however, are *not* part of the methodology. They were solely included to facilitate a comparison with other methods).

Figure 8 (next page) shows a print out of the environmental contributions from all phases of the plastic frame.

(Remark: In *none* of the case studies *radioactive waste* - resulting from nuclear power production - was taken into account, due to technical problems. The data on the next page therefore specify always a zero for radioactive waste. The deviation in the result is not significant, due to the fact that primarily Danish, i.e. non-nuclear, electricity is used in the models and because this exclusion was done in all cases.)

Miljø resultat	Beregning for plastvindue			
0vindue	PVC-vindue			
Miljøparametre				
UMIP niveau	Vægtning			
Mængde		1		
Levetid		40		
Vægtning 1	Ja			
Effekt-ID	Navn	**Fase**	**Mængde**	**Enhed**
1	Drivhuseffekt	MAT+ST.KOM	0,074230	mPET
10	Human TOX, vand	MAT+ST.KOM	0,026650	mPET
11	Human TOX, luft	MAT+ST.KOM	0,010160	mPET
12	Human TOX, jord	MAT+ST.KOM	0,010540	mPET
14	Øko TOX, vand-kronisk	MAT+ST.KOM	0,018680	mPET
15	Øko TOX, vand-akut	MAT+ST.KOM	0,042950	mPET
16	Øko TOX, jord	MAT+ST.KOM	0,092620	mPET
20	Volumenaffald	MAT+ST.KOM	0,046220	mPET
21	Farligt affald	MAT+ST.KOM	1,290000	mPET
22	Radioaktivt affald	MAT+ST.KOM	0	mPET
23	Slagge og aske	MAT+ST.KOM	0,010830	mPET
3	Forsuring	MAT+ST.KOM	0,055560	mPET
4	Fotokemisk ozon-1 (lavNOx)	MAT+ST.KOM	0,002229	mPET
5	Fotokemisk ozon-2 (højNOx)	MAT+ST.KOM	0,001935	mPET
6	Næringssaltbelastning	MAT+ST.KOM	0,017380	mPET
			1,699984	**mPET**
1	Drivhuseffekt	EGENPROD	0,014680	mPET
10	Human TOX, vand	EGENPROD	0,008671	mPET
11	Human TOX, luft	EGENPROD	0,001325	mPET
12	Human TOX, jord	EGENPROD	0,006441	mPET
14	Øko TOX, vand-kronisk	EGENPROD	0,008543	mPET
15	Øko TOX, vand-akut	EGENPROD	0,007964	mPET
16	Øko TOX, jord	EGENPROD	0,000020	mPET
20	Volumenaffald	EGENPROD	0,012420	mPET
21	Farligt affald	EGENPROD	0,000000	mPET
22	Radioaktivt affald	EGENPROD	0	mPET
23	Slagge og aske	EGENPROD	0,008080	mPET
3	Forsuring	EGENPROD	0,007186	mPET
4	Fotokemisk ozon-1 (lavNOx)	EGENPROD	0,000360	mPET
5	Fotokemisk ozon-2 (højNOx)	EGENPROD	0,000380	mPET
6	Næringssaltbelastning	EGENPROD	0,001816	mPET
			0,077885	**mPET**
1	Drivhuseffekt	TRANS IND	0,016260	mPET
10	Human TOX, vand	TRANS IND	0,000874	mPET
11	Human TOX, luft	TRANS IND	0,013320	mPET
12	Human TOX, jord	TRANS IND	0,000189	mPET
14	Øko TOX, vand-kronisk	TRANS IND	0,000683	mPET
15	Øko TOX, vand-akut	TRANS IND	0,000001	mPET
16	Øko TOX, jord	TRANS IND	0,000000	mPET
20	Volumenaffald	TRANS IND	0,000312	mPET
21	Farligt affald	TRANS IND	0,000000	mPET
22	Radioaktivt affald	TRANS IND	0	mPET
23	Slagge og aske	TRANS IND	0,000296	mPET
3	Forsuring	TRANS IND	0,011750	mPET
4	Fotokemisk ozon-1 (lavNOx)	TRANS IND	0,012260	mPET
5	Fotokemisk ozon-2 (højNOx)	TRANS IND	0,012660	mPET
6	Næringssaltbelastning	TRANS IND	0,007188	mPET
			0,075792	**mPET**
20	Volumenaffald	BORTSKAFF	**0,325200**	**mPET**
		Total:	**2,178862**	**mPET**

Figure 8: The figures behind the EDIP bar chart result for the plastic window frame and their summation in phases and in total (phases from top: Material Production, Manufacturing, Transport, Disposal)

A similar summarisation was performed for the wooden frame, as well. This one, however, is only reflected in **table 1** below. It shows the results of the summarised EDIP evaluation of the two window frames in mPETs. In order not to set exceeding focus on decimal places, all figures are rounded.

	Mat. Prod. [mPET]	Manuf. [mPET]	Transport [mPET]	Use* [mPET]	Disposal [mPET]	**Total [mPET]**	**Heat loss [mPET]*
Plastic	1.7	0.1	0.1	0	0.3	**2.2**	*1087*
Wood	> 0.0 ⊇	0.2	0.1	≈ 0	0.1	**0.4**	*1087*

Table 1: Summarised EDIP results for a plastic and a wooden frame compared to heat loss over 40 years through the glass pane

⊇: “Pressure impregnating“ of the wood is not included due to lack of data.

For comparative reasons, the heat loss through the window pane is mentioned as well. The figure represents the summarised EDIP result for 15 kg fuel oil - which is the estimated annual amount - multiplied by the 40 years life time.

Plastic frame
According to the figures in table 1, the plastic frame performs worse than the wooden frame. This is mostly due to the Material Production. Background for this circumstance is the fact that the plastic material extraction and processing causes a considerable amount of hazardous waste (1.29 mPET, see fig. 8). Manufacturing and Transport of the plastic frame result in no significant environmental harm.

The Use phase of the frame does not have any environmental consequences. However, as an interesting fact to be aware of in this context, the amount of mPETs resulting from the heat loss through the window *pane* is mentioned as well in the last column of table 1. Assuming a loss of 15 kg fuel oil per year over the life time of 40 years, this heat loss is equivalent to more than 1000 (!) mPETs. This figure is about 2000 times as much as the wooden frame and 500 times as much as the plastic frame!

Disposal of the plastic frame by landfill causes an amount of bulk waste which corresponds to 0.33 mPETs. A disposal scenario with incineration would have resulted in a considerably higher value due to the fact that the plastic frame mostly consists of PVC which in turn causes the well-known problematic emissions (highly dangerous chloride compounds (e.g. hydrochloric acid), dioxins and heavy metals [DEPA, 1996]).

Wooden frame
The Manufacturing phase in the wooden frame’s life cycle has a considerably high electricity consumption per frame which results in about twice as many mPETs as any other phase of this product. Compared to the plastic frame, Manufacturing of the wooden frame causes about twice as many mPETs. Due to lack of data, the process of pressure impregnating of the wood is not included in the evaluation. The actual figure for the Material Production phase will thus be higher.

3.1.3 The *Eco-indicator 95* evaluation results

In the Eco-indicator “Manual for Designers” [PRE, 1995], various indicators for materials, manufacturing processes, transport processes and other processes are pre-defined in specific units, e.g. milli points per kg, milli points per kWh. Those milli-points can be compared to the mPETs from the EDIP methodology. There are, however, substantial differences e.g. in the utilised bases for Normalisation and Weighting (see section 2.3).

Using the life cycle models and Inventories from section 3.1.1, suitable pre-defined Eco-indicators were simply multiplied by the respective amounts of e.g. material processed.

As an example, the calculation of the value for the Material Production of the plastic frame shall be described by means of the table below (see also fig. 2 again, figures rounded to one decimal place):

Phase: MATERIAL PRODUCTION

Material or Process	**Amount**	**Eco-indicator**	**Result**
PVC-granulate	5.9 kg	4.2 mp/kg	24.8 mp
secondary steel	6.2 kg	1.3 mp/kg	8.1 mp
rolling, warm *	0.58 m^2	2.0 mp/ m^2	1.2 mp
electroplating	0.58 m^2	22 mp/ m^2	12.8 mp
		TOTAL:	**46.9**

Table 2: Use of Eco-indicators for the quantification of environmental damage, shown by means of the material production for a plastic window frame

When certain indicators could not be found in the manual, worst-case oriented indicators were estimated wherever possible. This was for instance done for the production of the steel profiles by warm rolling, which is not pre-defined (see the * in table 2). In this case, an estimation was done which was based on cold-rolling of steel (0.46 mp/ m^2). Due to the assumed higher energy consumption compared to cold rolling, the value was set higher (factor four).

Such results - amounts of milli points for each phase - could finally be summarised to one score for the whole life cycle. This procedure is defined in the methodology. The comparative result of this evaluation is given in **table 3** on the following page.

	Mat. Prod. [mp]	Manuf. [mp]	Transport [mp]	Use* [mp]	Disposal [mp]	**Total [mp]**	**Heat loss [mp]*
Plastic	46.9	2.5	7.0	0	5.5	**61.8**	*4050*
Wood	> 8.2 ⊇	8.0	0.5	4.5 ⊄	0.2 ⊄	**21.4**	*4050*

Table 3: Summarised Eco-indicator results for the plastic and the wooden frame compared to heat loss over 40 years through the glass pane

⊇: “Pressure impregnating“ of the wood is not included due to lack of data.

⊄: estimates (for Disposal based on similar indicators)

The figures of **table 3** ascertain a better environmental result for the wooden frame than for the plastic one. The result for the wooden frame, however, is rather insecure due to the omission of “pressure impregnation” and the two estimations for Use and Disposal.

Plastic frame

The Material Production is the biggest source of impact potentials in the plastic frame’s life cycle. The Manufacturing involves about 3 kWh electricity per frame, which is not significantly much. This is mirrored in the relatively low mp-value.

Transport, however, results in the second highest mp-value. The biggest contribution to this result comes from about 20 ton-kilometres (tkm) truck transport which are equal to 6.77 mp. Train and ship transport have considerably lower indicators (about 1/10 of truck) and contribute only with a total of 4.8 tkm.

In the Use phase, the interesting point is again the immense heat loss through the window pane with its environmental consequences. The figure for the Disposal of the plastic frame is dominated by the steel frame which is responsible for nearly 5 mp.

Wooden frame

The most important contributions to the wooden frame’s Material Production phase are the mechanical wood processes (nearly 7 mp) and the drying of the wood (1.5 mp). The high energy consumption of the Manufacturing phase (about 12 kWh/frame and 0.67 mp/kWh) characterises this phase.

The wooden frame doesn’t weigh too much, involves a lot of efficient ship transport and is transported over relatively short distances. This is the reason for the comparatively low figure for Transport.

Painting of the frame (9 times or 5 m^2 in total) in the Use phase and landfilling in the Disposal of the frame are not defined with Eco-indicators. While for painting an indicator of 0.1 mp/m^2 had to be guessed (due to missing comparable ones), the indicator for landfill could be estimated by means of other disposal processes. The indicator for painting may well be much higher, which lets this phase appear to probably be the most important one of the wooden frame’s life cycle.

3.1.4 The *Oil Point* evaluation results

For the evaluation by means of an energy balance, a unit describing the energy content of 1 kg oil was defined. The unit was called “Oil Point” (OP) and represents the energy value of 45 MJ, see section 2.4.

A core element in this method is the fact that it works after the principle of rough data respectively good estimations combined with simple calculations. The method is assumed to give quick but still - compared with comprehensive methods - “correct” results in the order of magnitude because energy consumptions are responsible for a major part of potential environmental impacts.

In the comparison of two different materials to be used for an application in a specified life cycle, the conclusion could for instance be that one material would be preferable to another. Such conclusions to be drawn from “Oil Point” calculations are expected to be similar to the ones from other, more complex methods.

For the further calculations, the same life cycle model as for the other two evaluations was used in order to make the results obtained by this method comparable to the ones from the EDIP and Eco-indicator calculations. For this reason, a couple of Oil Point indicators for major energy consuming processes had to be defined. These definitions give a relatively rough picture of real amounts and values involved but thus mirror the character of the method. They are listed below:

1 kg oil = 1 OP = 45 MJ

Electricity:	0.25 OP/kWh	(1 kWh ≈ 10 MJ (incl. efficiency factors) ≈ 0.25 OP)

Truck-transport:	10 OP/1000 tkm	(from: 40 kg crude oil per 100 km at 40 t total weight of the truck)

- Plastic-granulate:
  - heating value: 45 MJ/kg = 1.0 OP/kg
  - process energy: 22 MJ/kg ≈ 0.5 OP/kg (for extraction)
  - => 1.5 OP/kg
- Wood: 0.1 OP/kg (from ≈ 5 MJ/kg process energy)

Based on these definitions of Oil Point indicators and one estimate (for electroplated steel), the evaluation of the products took place in a quite similar way to the Eco-indicator 95 method: The amount of material was simply multiplied by the respective Oil Point indicator. The complete calculation of the values for the plastic frame can therefore be presented in just one table. This table is shown below:

Life cycle phase	**Material or Process**	**Amount**	**OP-indicator**	**Result**
Material Production	plastic-granulate	6 kg	1.5 OP/kg	9.0 OP
	electroplated steel	6 kg	0.7 OP/kg *	4.2 OP
Manufacturing	electricity	3.7 kWh	0.25 OP/kWh	0.9 OP
All Transport	truck transport	20 tkm	10 OP/1000 tkm	0.2 OP
Use	-	-	-	0 OP
Disposal	-	-	-	0 OP
			TOTAL:	**14.3 OP**

Table 4: Use of Oil Point indicators for the quantification of potential environmental impact, shown by means of a plastic window frame

* The indicator for electroplated steel is estimated based on the plastic-granulate indicator.

Similar estimations based on data from literature and experience are explicitly allowed in the method.

According to the energy balance result, the by far most important phase of the plastic frames' life cycle is the Material Production. Within this phase, it is the plastic-granulate which is responsible for about two thirds of the energy consumption.
The estimated rest is necessary for the steel production and its electroplating. The major part of the electricity (2.7 kWh) is used for producing the actual profile. Only about 1 kWh goes into the window production. Use and Disposal of the window frames are not connected to any significant energy consumption. The complete calculation for the wooden frame is shown in **table 5**.

Life cycle phase	**Material or Process**	**Amount**	**OP-indicator**	**Result**
Material Production	wood	9 kg	0.1 OP/kg	0.9 OP
	electricity (for drying)	2.3 kWh	0.25 OP/kWh	0.6 OP
Production	electricity (processes)	12 kWh	0.25 OP/kWh	3 OP
All Transport	truck transport	1.1 tkm	10 OP/1000 tkm	≈ 0 OP
Use	-	-	-	0 OP
Disposal	-	-	-	0 OP
			TOTAL:	**4.5 OP**

Table 5: The Oil Point result for the wooden window frame

According to this calculation, the Material Production results in about one third of the overall potential environmental impact. The most relevant phase, however, is the Production where a considerable amount of electrical energy is consumed.

The heat loss through the window pane over the 40 years of life time was just calculated as follows: 15 kg oil /year x 1 OP x 40 years = 600 OP

A comparison of the two Oil Point results including the heat loss is shown in the next section, together with a summary of all other previous results.

3.1.5 Summarised result and conclusions of the window-frame case

	Window Frames					
	Plastic			**Wood**		
	EDIP [mPET]	E.-i. 95 [mp]	Energy [OP]	EDIP [mPET]	E.-i. 95 [mp]	Energy [OP]
Material Production	1.7	46.9	13.2	> 0.0	> 8.2	1.5
Manufacturing	0.1	2.5	0.9	0.2	8.0	3
All Transport	0.1	7.0	0.2	0.1	0.5	≈ 0
Use*	0	0	0	≈ 0	4.5 ⊇	0
End-of-life	0.3	5.5	0	0.1	0.2 ⊇	0
Total:	**2.2**	**61.9**	**14.3**	**0.4**	**21.4**	**4.5**

**Heat loss 40 x 15 kg oil:*	*1087*	*4050*	*600*	*1087*	*4050*	*600*

Table 6: The results of the window frame case
⊇: based on estimates

This table shows the results of all three evaluations in the window frame case separated into phases. The EDIP figures are generated using the LCV-tool while Eco-indicator and Oil Point results are calculated "manually".

The wooden frame performs better than the plastic one in all evaluations. Both for plastic and for wood, the tendency of the energy figures is the same as for the EDIP figures. The different tendency of the Eco-indicator values can be considered as based on different normalising and weighting criteria.

For reasons of comparison, the last row of the table gives methodology-specific figures for the amount of energy that is lost through the window pane over the whole life time of 40 years. This comparison shows that the environmental impact caused by the frame, however, is only a fraction between 1/3 and 1/1000 of the impact caused by the loss of energy through the glass. The difference between the two materials and process chains is thus negligible in relation to the overall performance of the product. The major environmental impact of the whole window occurs during the use phase. Although the evaluations were focused on the frame, where wood performs better than plastic, a holistic contemplation leads to the conclusion that the selection of a different type of *glass* would be appropriate in order to improve the overall environmental performance.

In this case study, it is important to be aware of the fact that the main result - i.e. that wood performs better than plastic - is highly dependant on the assumed life cycle of the product. If, for instance, recycled material would have been contemplated which then would be recycled again, the result may probably have been in favour of the plastic frame.

With respect to the size of this paper, the following two case studies on active and textile products are only described by tables with their comparative results and by remarks to assumptions and estimations.

3.2 Case 2: A coffee machine - as example for active products

Active products, i.e. products which have to consume energy in order to provide their functionality, typically have the highest environmental impact potential resulting from this energy consumption during use. The most important phase in the life cycle of such products is therefore typically the use phase, compare e.g. [DANNHEIM ET. AL., 1997]. For the coffee machine, a similar result can be expected. Aim with this case study is therefore primarily to investigate correlations between the methods rather than to analyse the product or to compare it with product alternatives.

3.2.1 The life cycle of the coffee machine

Figure 9 on the following page shows the life cycle of a coffee machine. The example is taken from the Eco-indicator manual [PRE, 1995]. The model and data given here have been used for the EDIP evaluation (done by means of the LCV-tool) and the energy evaluation. This means that again all three evaluations are based on the same figures.

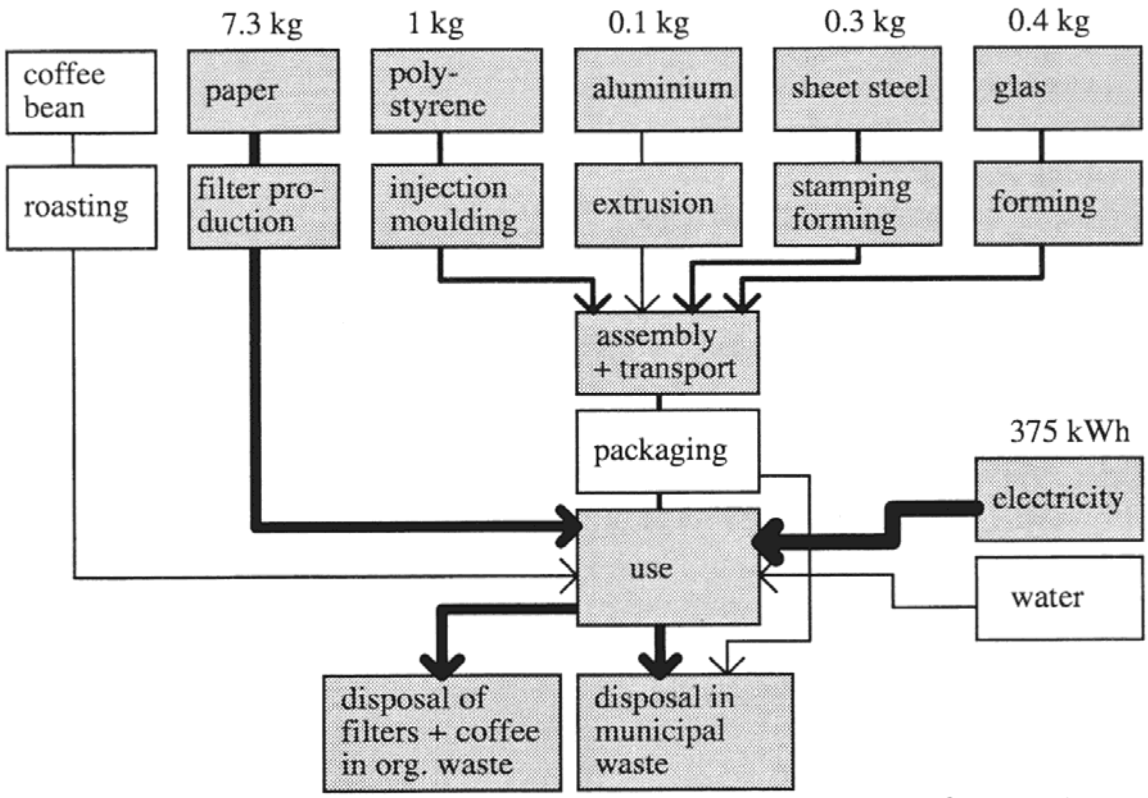


Figure 9: The life cycle of a coffee machine [PRE, 1995]

The coffee machine consists of a polystyrene housing, a glass jug, a steel hot plate and an aluminium riser pipe. Cables, switches and packaging are omitted just as the coffee beans and the consumed water (see the white building blocks in figure 9).

The coffee machine is assumed to have a life time of 5 years where it is used twice a day. One use includes a brewing of 6 cups (i.e. half capacity) and a period of 30 minutes of keeping the coffee hot. The disposal scenario is incineration.

Some inventory data are given in figure 9. The relative amounts are indicated by the thickness of the arrows.

The main Inventory data for the whole product life cycle are as follows, see [PRE, 1995]:

- 1 kg of polystyrene, to be injection moulded
- 0.1 kg of Aluminium, to be extruded
- 0.3 kg sheet steel
- 0.4 kg glass
- 7.3 kg paper (chlorine-free bleached)

- 4 tkm truck transport (assumption of e.g. 4 kg transported over a distance of 1000 km)
- 375 kWh electricity (5 years life time, 2 brewings per day at half capacity incl. 30 min on hot plate, about 0.1 kWh per brewing; based on measurements)
- disposal via municipal waste and incineration

Transport data are not included in the example of [PRE, 1995]. Therefore, a transport scenario within Europe has been added by the authors (see above).

Based on these data, the three evaluations of the coffee machine were made. For this reason, an EDIP model, comparable to the ones of figures 5 and 6, was built.

The energy evaluation is explained by the subsequent **table 7**.

LC-phase:		45 MJ/kg = 1 OP/kg	
Material Production			**Process energy**, [Jepsen, 1978]
2.8 OP	1 kg Polystyrene	2.8 OP/kg	124 MJ/kg (incl. 45 MJ/kg heating value)
0.6 OP	0.1 kg Aluminium (primary)	5.8 OP/kg	260 MJ/kg
0.2 OP	0.3 kg Sheet steel	0.7 OP/kg	33 MJ/kg
0.2 OP	0.4 kg Glass	0.4 OP/kg	19 MJ/kg
3.8 OP			
Manufacturing			
1.4 OP	1 kg injection moulding	**1.4 OP/kg	** estimate (1/2 of PS production)
0.01 OP	0.1 kg extruding	*0.07 OP/kg	* estimate (1/10 of sheet manufacturing)
0.02 OP	0.3 kg sheet pressing (thin)	*0.07 OP/kg	* estimate (1/10 of sheet manufacturing)
0.1 OP	0.08 kg natural gas (fuel)	1 OP/kg	
1.53 OP			
All Transport			
0.004 OP	*4000 kgkm lastbil	10 OP/1000 tkm	* estimate
0.004 OP			
	5 years x 365 days/year x 2 brewings/day = 3650 brewings		
Use			
93.8 OP	375 kWh electricity	0.25 OP/kWh	3650 brewings x ca. 0.1 kWh
3.7 OP	7.3 kg paper	0.5 OP/kg	23 MJ/kg and 3650 brewings x 2 g paper
97.5 OP			
End-of-life			
- 1 OP	1 kg PS, incineration	1 OP/kg	45 MJ/kg (heating value)
0 OP	0.1 kg Alu, incineration		
0 OP	0.3 kg sheet steel, incineration		
0 OP	0.4 kg glass, incineration		
- 2.2 OP	7.3 kg paper, incineration	0.3 OP/kg	15 MJ/kg estimation, based on wood
- 3.2 OP			
TOTAL: 99.6 OP			

Table 7: Evaluation of the coffee machine according to the Oil Point method

3.2.2 Summarised result and conclusions of the coffee machine case

Table 8 (next page) summarises the evaluation results for the coffee machine. As expected, all three evaluations exhibit the use phase as the one with the by far highest environmental impact potential in the machine's life cycle. The material production phase is ranked at the second place in all results - however with a much lower impact potential. The contributions from end-of-life phase and manufacturing phase are comparably very low. As mentioned earlier, this result can be considered as being typical for active products (see also [EDIP, 1997], p.369 ff., the TV case).

	Coffee Machine		
	EDIP [mPET]	Eco-indicator 95 [mp]	Energy [OP]
Mat. Prod.	1.2	12.2	3.8
Manufacturing	0.2	1.0	1.5
All Transport	0.0	0.1	≈ 0 ⊇
Use	37.4	275	97.5
End-of-life	1.0	3.3	- 3.2
	39.8	**291.6**	**99.6**

Table 8: The results of the coffee machine case
⊇ The value lies just above zero

The high values of the use phase originate mostly from the energy consumption for brewing coffee. However, as can be seen in table 8, the consumption of paper filters contributes also considerably. Potential environmental impacts from the material production are the third biggest contribution. A conclusion to be drawn from these figures is that further product improvements should focus on measures to reduce energy consumption during the use of such a product. A secondary aim would be the reduction of filter paper.

Supporting the aim of this paper, it shall be pointed out again that the result of the energy based evaluation is basically the same as the other two results. Main conclusions to be drawn are identical as well. In the final case study, two textile products were examined by all three evaluation methods.

3.3 Case 3: Two sweaters - as example for textile products

3.3.1 The life cycles of the sweaters

Subject in this case were two sweaters: one made of 100 % polyethylene-terephtalate (PET) and one made of 100 % cotton. For this case study, some data from a preliminary project on LCA of textile products have been utilised [UMIPTEX, 1998] combined with data from a report from the Danish Environmental Protection Agency (DEPA) on environmental assessment of textiles [DEPA, 1997].

The material production phase as well as the manufacturing phase for textiles comprise several steps. While material production stands for all steps of the production of fibres from raw material, manufacturing means all processes that are necessary to manufacture a finished product, e.g. a knitted sweater, from the fibres. In the UMIPTEX pre-project, all steps of material production respectively of manufacturing have been considered in combination. Therefore, the life cycle models of the present case study just consist of one condensed phase of material production and one condensed phase of manufacturing.

The subsequent phase is ”transport” - ca. 1.5 ton-kilometres for the cotton sweater and about half as much for the PET sweater. The use phase consists of 75 times washing and tumble-drying. In the end-of-life phase, 75 % of the sweaters are incinerated and 25 % disposed of by landfill. The sweaters are assumed to have a weight of 1 kg each. For both sweaters, 3 kg of fibres are necessary.

A summary of the used inventory data is given below.

Both sweaters:
- 1 kg weight,
- 75 x washing and drying, (e.g. every second week over ca. 3 years),
- not coloured

Cotton:
- 100 g semen, 3 kg cotton, processing to fibres, 4 kWh electricity, 0.7 kg fuel oil, 3.5 MJ unspecified primary energy, 4 m^3 water/ kg cotton
- 13.6 kWh, 0.9 kg fuel oil and 0.1 kg gas oil during 5 manufacturing steps
- 1.5 tkm truck transport,
- 19.5 kg fuel oil, 1.5 kg washing powder, 1.8 m^3 water during use
- 75 % incineration, 25 % landfill (heating value ca. 12 MJ/kg)

PET:
- 3 kg PET granulate from crude oil, processing to fibres,
- 2.6 kg fuel oil, 0.2 kg gas oil during 5 manufacturing steps,
- ca. 0.8 tkm truck transport
- 18 kg fuel oil, 1.5 kg washing powder, 1.8 m^3 water during use
- 75 % incineration, 25 % landfill (heat value ca. 23 MJ/kg)

The mentioned heating values have been taken from the LCV computer tool which was again used for the EDIP evaluation.

3.3.2 Summarised result and conclusions of the sweater case

The results of the three evaluations are shown below.

	Sweaters					
	PET			**Cotton**		
	EDIP [mPET]	E.-i. 95 [mp]	Energy [OP]	EDIP [mPET]	E.-i. 95 [mp]	Energy [OP]
Material Production	9.7	22.8	2.4	4.1	**?**	1.8
Manufacturing	8.7	19	2.8	11.2	**?**	4

All Transport	0.1	0.3	+ 0 $^{\supseteq}$	0.2	0.6	+ 0 $^{\supseteq}$
Use	32.4	126.5	19.3	33.7	132.5	19.9
End-of-life	0.5	1.4	- 0.4	0.4	2.0	- 0.2
Total:	**51.4**	**41.8 + 128.2**	**24.1**	**49.6**	**? + 135.1**	**25.5**

Table 6: The results of the textile case
$\supseteq$: the value is just above zero

EDIP figures
Comparing the two sweaters by means of the EDIP figures, two comments can be made:
1. The use phase, i.e. washing and tumble drying, has the highest impact potential for both materials
2. In the overall result, cotton performs slightly better than PET but the results are not significantly different from each other.

Eco-indicator figures
There are no Eco-indicators defined for cotton production or cotton manufacturing processes. This makes a proper comparison of this material with PET impossible. However, calculations for transport, use and end-of-life were possible. For the use phase, Eco-indicators for water consumption and washing powder were estimated. A comparison of these figures indicates a better performance of the PET sweater and the importance of the use phase for this result.

Energy figures
Similar to the preceding evaluations, the Oil Point evaluation stresses the importance of the use phase for textiles, even though washing powder and water consumption have not been taken into account in this evaluation. Although the material production of the PET sweater is based on non-renewable non-recycled material, the comparatively lower energy consumptions during manufacturing and use of this material are reason for an overall slightly better performance of the PET sweater.

In the important use phase, cotton performs worse than PET in all three evaluations. This is probably due to the fact that the cotton fibres absorb more water which afterwards takes more energy for drying. The selection of a material which absorbs the smallest amount of water and/or the inclusion of a coating process would be an appropriate measure of product improvement here. Transport processes are practically unimportant in all evaluations.

While the total result of the EDIP evaluation is better for the cotton sweater than for the PET sweater, the result of the energy evaluation is just the opposite. However, in both evaluations the results lie very close to each other. Comparing the single phases of the life cycle, the energy figures show exactly the same tendencies as the EDIP figures. This indicates, that it is primarily the energy consumption which is responsible for the potential impacts in this example.

4 Conclusions and Future Work

In this paper, a method is presented which is intended to help designers when trying to evaluate sustainability aspects in their daily work. Facing the fact that there are - environmentally speaking - different categories of products (e.g. passive, active and textile) and again different methods for evaluation with different inherent degrees of complexity, it was decided to conduct a set of case studies in order to have examples for the application of the different methods on the different product categories.

The results of the case studies were subsequently presented in two workshops and discussed with designers, product developers and LCA experts. One aim with the workshops was to find out, which of the methods would be suitable for the designers' situation. As a main outcome, none of the methods was found to be generally best appropriate.

Product developers emphasised the depth of information supplied by EDIP results. It is not only possible to *detect* a certain critical material or manufacturing process but also to find out *why* this is so. This gives the product developer a lot more space for case-specific decisions than single-score methods in general can do. Industrial designers, however, were more interested in getting more general, non-technical information. They found detailed information to be too confusing in the creative process.

In the case studies themselves, three environmental evaluation methods were utilised: The EDIP methodology, the Eco-indicator 95 and the Oil Point method, proposed by the authors, which is related to energy consumption. The major result of the case studies was that the Oil Point method in the first two cases (passive resp. active products) lead to identical main conclusions as the two other by far more comprehensive evaluation methods. In the last case study (textiles) only the tendencies in the single phases were similar, not the overall result. Due to the comparatively short time an energy-based evaluation can be performed in and due to the fact that it is relatively easy to comprehend, this method appears to be very useful for the rough evaluation of product concepts by designers.

A couple of other conclusions shall be mentioned in the form of a dotted list:

• "Think in life cycles - also when deciding upon material/manufacturing alternatives":
The case studies stressed the well-known circumstance that it is crucial to contemplate whole life cycles even if only a decision between different material and thus manufacturing alternatives has to be made. Comparing certain phases only leads to incomplete results. In the window frame case, for example, the assumed material origin and end-of-life scenario have a decisive influence on the question whether wood or plastic is more environmentally friendly.

• Data quality/ sensitivity:

LCA - even when supported by computer-tools - is a complex affair. The presented data have to be considered as partially insecure or even faulty. This is mainly due to the fact, that the case studies only represent first or second iterations. Further iteration cycles would probably lead to more trustful data. With respect to the quality of energy data, a sensitivity analysis is strongly recommended because energy data given in the literature often differ largely. In the scope of a sensitivity analysis key figures are identified and the overall variability of results and conclusions as a consequence of uncertainties in these key figures is analysed. Furthermore, it is often not clearly stated, whether given secondary energy data (e.g. electricity) are *efficiency-corrected* or not. The difference between them, however, is a factor of about 3 (!). The same problem applies to secondary energy data (usually given in kWh) calculated from primary energy (usually given in MJ) and vice versa.

• Effect of data quality on the main conclusions concerning the methods:
In spite of the not fully trustful data basis, the main conclusions of the presented case studies are considered to be tenable because all three evaluations in each case are based on the *same* (good or bad) data.

• Missing information:
Missing Eco-indicators or unit processes in the EDIP tool represent a problem. In these situations, estimates have to be used. Estimated Eco-indicators should best be orientated at existing indicators. Missing or "bad" data are an LCA-inherent problem.

• Weaknesses/ Deficiencies of the Oil Point method:

- Chemicals can influence LCA results decisively but are not taken into account in the method. Chemicals had to be omitted in the wooden frame case due to lack of data on the paint and the impregnation processes. The textile case, however, showed that the main results were independent from chemicals like the washing powder.
- In the present state, the method depends very much on low quality data like assumptions and averages (this deficiency, however, may be overcome in the future by establishing a growing set of reliable data)

• Strengths of the Oil Point method:

+ The method can build the basis for fairly good evaluations
+ Such rough evaluations can be obtained relatively quick
+ The method is easy to understand
+ There is a large amount of energy data in the literature
+ In the case study results, same tendencies as in the results of the more complex methods have been documented.

And

Also LCAs involve many assumptions and thus a degree of uncertainty
Already the Inventory of an LCA has often to be based on non-precise data, i.e. averages and assumptions.

Future work

Due to the high possible influences of chemicals, e.g. in form of dioxin, chemical aspects have to be considered as well, at least on a qualitative level. In the window frame case, chemicals had to more or less be avoided even in parts of the EDIP model. The reason was lack of data. If all chemicals would have been taken completely into account, the result would most likely have been another one - at least for certain phases in the life cycle.

Investigations of influences from chemicals on Oil Point evaluations could focus on certain chemicals or product groups. Related questions to answer are e.g.:

- How strong an influence can chemicals actually have on the result?
  (in terms of how "wrong" the result otherwise gets)
- What are average figures of chemical influence?
- Which kinds of chemicals have to be considered?
- Is it possible to focus on just a few substances, which are most important?
- What are relations between product groups and chemicals?
- Are there certain product groups where chemicals can be neglected?

etc.

With respect to application, it has to be defined in which way data on chemical substances should be incorporated in the Oil Point method.

In order to make a future method reliable in its result, the data quality has to be improved substantially. This is especially with respect to the idea that such data shall also be used for estimations. Utilised data must therefore not have a wide range like e.g. 5-20 MJ/kg etc.

Finally, for making a method practically usable, a comprehensive set of manufacturing process and material data have to be collected. Due to the wide application and existence of energy data, it is assumed that such collection may well be accomplished in a reasonable period of time. The collection of chemical data is presumed to be more problematic but feasible as well.

A method based on reliable energy data supplemented by chemical information should then be capable of facilitating relatively quick evaluations of concepts on an adequate level of accuracy compared to comprehensive LCA methodologies.

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