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ENVIRONMENTAL IMPACT ASSESSMENT IN DESIGN OR IS IT WORTH IT TO CARRY OUT A FULL LCA?

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Abstract

Since 1996 the Collaborative Research Center (CRC) 392 has been working in the field of Design for Environment (DFE) at the Darmstadt University of Technology. In lectures and seminars it was found that the students achieved very good, sometimes astonishing results, considering their lack of environmental and professional experience and tough time schedules. The students just used ready-made Eco-indicator 99 (EI 99) scores to identify weak-points and to derive a requirements list. The situation for the students is similar to the conditions often found in industry: time pressure and limited environmental expertise. Based on these experiences within the course the question arose as to whether or not it is advisable to carry out a full life cycle assessment (LCA) to derive a requirements list during the task clarification. Therefore, the paper discusses open issues, based on these experiences and on the expertise gathered in cooperation projects with industry, as well as the sense and non-sense of a full LCA in product development. **This discussion is from the viewpoint of a product developer and not that of an LCA expert.** At the end the paper suggests a procedure to carry out an environmental impact assessment within the product development process.

Keywords: case study, life cycle assessment, environmental requirements, early phases of design, introduction of methods in industry

1 Introduction

Since 1996 the Collaborative Research Center (CRC) 392 has been teaching Design for Environment (DFE) at the Darmstadt University of Technology. In the project seminar, graduate students in interdisciplinary teams of four must environmentally improve a consumer product. The results were very good, sometimes astonishing, considering the lack of environmental and professional experience and the tough time schedule. At the beginning of the project the students carried out an environmental weak-point analysis using ready-made Eco-indicator 99 (EI 99) scores from the Manual for Designers [1] and from the IdeMat database [2]. Based on the identified weak-points the students derived a requirements list for the product to be improved.

The conditions within the seminar are similar to those often found in industry: the pressure of deadlines and limited environmental expertise. Therefore, a compromise between the accuracy of the results and the effort put into the results must be made. Due to this fact, the students used ready-made EI 99 scores to assess the environmental impacts of the product. The requirements list included all relevant requirements. Based on these experiences, the question arose as to whether or not it is advisable to carry out a full life cycle assessment (LCA) to derive a requirements list during the task clarification.

2 Goal of the paper

The goal of the paper is to show why in a lot of cases it is enough to carry out a rough environmental assessment using existing EI 99 scores to effect an environmentally conscious product development. For this, the phase of a full LCA will be described and the problems occurring during the LCA process will be discussed using appropriate examples. The questions which arise are real questions that were raised while carrying out normal LCAs. Additionally, case studies are used to show that, in many cases, EI 99 scores alone are sufficient. In general, the paper discusses open issues as well as the sense and 'non-sense' of LCAs in product development.

The questions and answers are raised and given from the viewpoint of a product developer and not that of an LCA expert.

3 Life cycle assessment (LCA)

According to the ISO 14040 : 1997, an LCA includes the following phases: definition of the goal and scope, inventory analyses, impact assessment, and interpretation of the results (Figure 1).

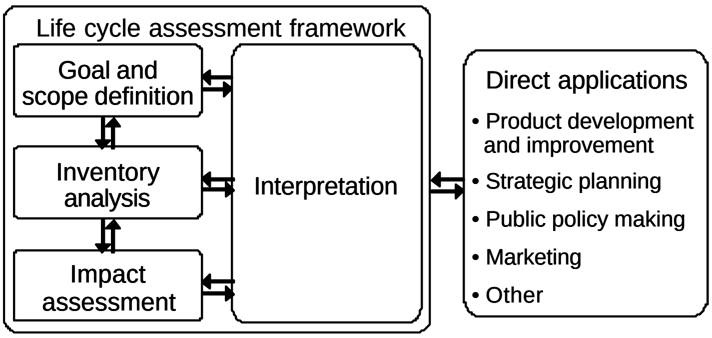

Figure 1. Phases of an LCA (ISO 14040 : 1997)

3.1 Definition of the goal and scope

The goal and scope of the LCA should be clearly defined and consistent with the intended application.

Definition of the goal

Beside the reason for carrying out the LCA study, the intended audience must be established in the goal definition. To limit the effort for carrying out an LCA it is advisable to carry out a comparative assertion which is closed to the public.

This way it is possible to exclude some in- and output data. When comparing two coffee makers, e.g., it is possible to neglect the coffee production and its transportation without any loss in validity since the process parameters are fixed for making a cup of coffee with the same flavor quality, and therefore, the amount of coffee is independent from the principle of coffee brewing and the maker.

Furthermore, if the results are only used in the product development process (closed to the public) it is not necessary to take the study under a critical review.

Definition of the scope

To define the scope for the goal “Comparing a manual and an electrical citrus press (Figure 2), to find out which has fewer environmental impacts and to get an idea of how to environmentally improve citrus presses” different aspects must be considered.

The materials, the amount of materials, and the electricity consumption during the use phase, clearly indicate that the environmental impacts of the electrical citrus press are higher compared to those of the manual citrus press. The goal, however, was not only to figure out which citrus press has a lower environmental impact, but also to get an idea of how an environmentally improved citrus press looks. Thus, a full LCA is carried out.

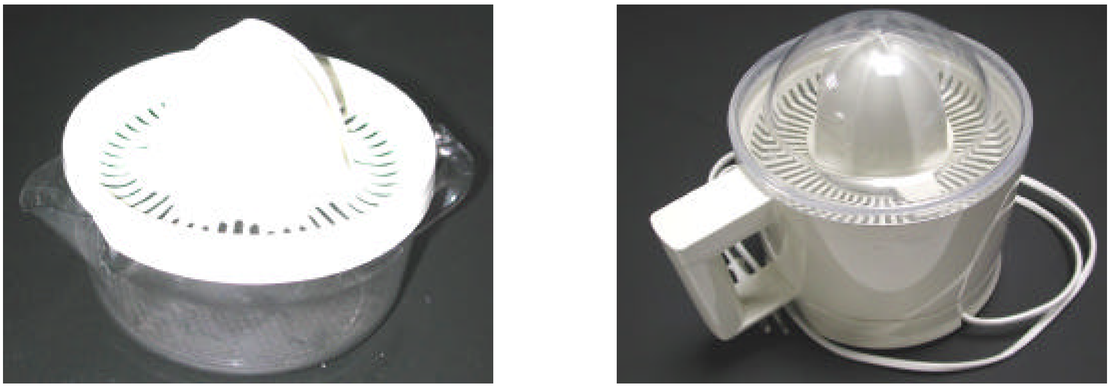

Figure 2. Comparison of a manual and an electrical citrus press

In order to do so, the function of the two product systems has to be defined as “separating the juice from the pulp”. The functional unit is to “make two glasses (0.2 l each) of orange juice per day from the beginning of November to May (180 days) over a life time of 8 years”. The functional unit is used as a reference and is, therefore, very important. It must be clearly defined and measurable since the in- and output data are normalized to it.

The reference flow must be determined by calculating the amount of products necessary to fulfill the functional unit. For this, the life time of the citrus presses is used: For the manual citrus press only ¾ of the products and for the electrical citrus press 1.5 products are used to fulfill the functional unit.

With this knowledge it is possible to define the initial system boundaries. The system boundaries are “initial” since everything within the definition of the scope is subject to change and must be adjusted during the LCA study, if necessary. It is not an easy task to decide whether the in- and output of a process is in- or outside of the system boundary. As an example, a question similar to the one for the coffee maker is raised: Should the practitioner consider the citrus fruit production and its transportation to be within the system boundaries? In this case the answer is yes, since the juice yield of the citrus press is not equal, and therefore, more oranges must be transported for the manual citrus press in order to make 0.4 l of orange juice (for more details see also 3.2). This is just one example for defining the system boundaries and the problem of the cut-off criteria. The system boundary must describe the interfaces between the product system, the environment and other product systems. It is helpful to use a process flow diagram in defining the system boundaries, which describes the unit processes and their interrelation.

These two simple examples of the coffee maker and the citrus press show already how difficult the definition of the goal and the scope are and how important it is to thoroughly carry out all steps.

The issue of describing the data categories, the criteria for the initial inclusion of in- and output, as well as the data quality requirements will not be dealt with in the paper. The data categories as well as the data (with their quality) are taken from SimaPro 5.0 software and its databases. The data quality is sufficient for the internal comparison. But it is important to recognize that using data from different sources, provided within one software tool, vary in the quality, and therefore, different results might be achieved even while using one single software tool. Furthermore, no critical review has been carried out for this internal review. More information about the goal and scope definition can be found in the ISO 14041 : 1998.

3.2 Life cycle inventory analyses (LCI)

The most important steps of the inventory analyses are described in Figure 3. In the following section problems which might occur are briefly described. For further information the ISO 14041 : 1998 can be consulted.

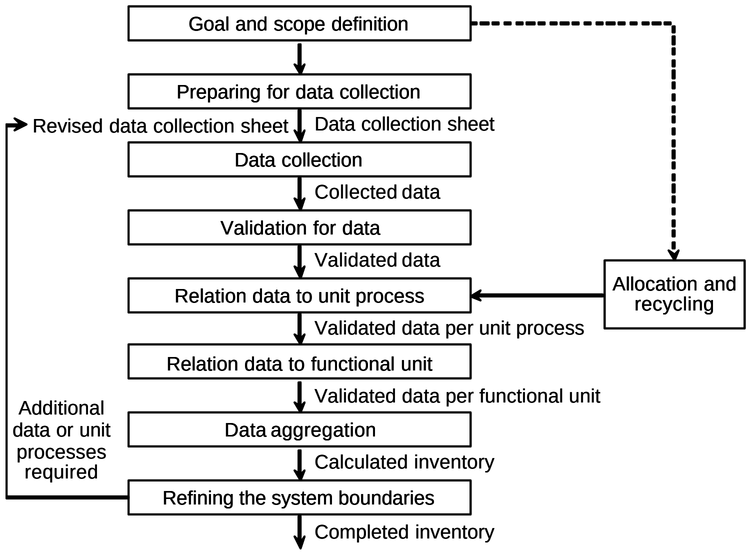

Figure 3. Simplified procedures for inventory analyses
(some iterative steps are not shown, compare ISO 14041 : 1998)

A form for the preparation of the data collection can be found in Annex A of ISO 14041 : 1998. For the actual data collection different procedures are used. In this paper the data collection for the use phase of the two citrus presses is partly described. One question is how many oranges are needed to extract 0.4 l of orange juice. The juice yield of the different citrus presses is empirically determined by carrying out experiments. During these pressing experiments the energy consumption of the electrical citrus press is measured using a watt-hour meter. For 4 oranges (1 Orange = 250 g), from which 0.4 l of juice is extracted, 1.3 Wh are used. The juice yield of the manual citrus press is 5 % lower than that of the electrical citrus press, and therefore, 4.2 oranges are needed.

How difficult the data collection process is can be imagined if the substances of lacquer, the additives of plastics, like flame-retardant, or the production of electronic parts, like resistors or capacitors, must be determined. Taking the resistor as an example, to what extent should the practitioner include processes belonging to the resistor? Within the resistor, ceramic is used as an isolator. This ceramic must also be produced for which quartz is needed. The quartz must first be extracted from rocks. The extracted quartz must then be milled, mixed with the other substances, and sintered. The "machines" for the quartz extraction, mixing and sintering must be produced, as well. After all this, the quartz must be transported. The transportation vehicles, which consume energy, must also be produced, etc. The question now is where to draw the line? No general answer can be given; in most cases the capital goods can be neglected, but in some cases this is not possible.

In any case, the validation of the data must be ensured. Gaps in the data must be documented. The data must be related to the unit process (reference flow) and the functional unit. The data should be only aggregated to a sufficient level appropriate to the goal of the study. The system boundaries must be refined according to the analyses.

Allocation is also a big problem in inventory analyses. Allocation is necessary when a process has more than one in- or output, so that the environmental releases of the flows must be allocated to the different products. Examples can be found during the material production, manufacturing or recycling processes where a lot of coproduction occurs. During the use phase of the citrus press, the problem of cleaning the citrus pressarises. This could be done in a sink with water together with other dishes, so the amount of the environmental impacts caused by the water, heating the water, and the detergent must be proportionately allocated to the citrus press and to the rest of the dishes. For this a user questionnaire must be carried out to gather information about peoples' dish-washing habits.

If the practitioner uses data from existing databases (a good and general database can be found under: http://www.ecoinvent.ch/en/index.htm), he/she has to consider four additional problems: the quality (completeness and reliability), the age (e.g. old vs. new machines), the geographical variation, and the technology (e.g. good vs. bad machines) of the data.

That is the reason why the inventory analyses must be interpreted: a quality assessment and a sensitivity analysis must be carried out for the significant in-, output and methodological choices.

3.3 Life cycle impact assessment (LCIA)

The life cycle impact assessment consists of the following mandatory elements: selection of impact categories, category indicators, and models, as well as the assignment of the LCI results (classification) and the calculation of the category indicator results (characterization). The optional elements include the calculation of the magnitude of category indicators relevant to reference information (normalization), grouping, weighting and data quality analysis.

In the case of an LCA, existing impact categories, category indicators and models, classifications, as well as characterization are selected so that these elements are not further discussed in the paper. Further information on this topic can be found in ISO 14042:2000.

The results of these mandatory steps are - at least for a product developer – not easily interpretable, and therefore, the optional elements are used to get a better understanding of the relative magnitude for each indicator result. The indicator results can be normalized by dividing them by a reference value, e.g. the total emission, total resource use for a given area or the total values per capita basis, or the compared product. To reach a single score the impact categories can be grouped and weighted. This process is based on value-choices and not on natural science. This single score can then be used to compare two products, parts, or material alternatives during the product development process.

Different methods exist for the impact assessment. In SimaPro 5.0, e.g., Eco-indicator 99 (**E**alitarian/**I**ndividualist/**H**ierarchist) [1], CML method 1992, CML 2 baseline method (http://www.leidenuniv.nl/interfac/cml/lca2/index.html), EDIP/UMIP [3], EPS 2000 (http://www.cpm.chalmers.se/cpm/publications/EPS2000.PDF) are included. Applying these different methods to evaluate a simple hair dryer gives confusing results (at least for a product developer). Two results are exemplarily shown in Figure 4.

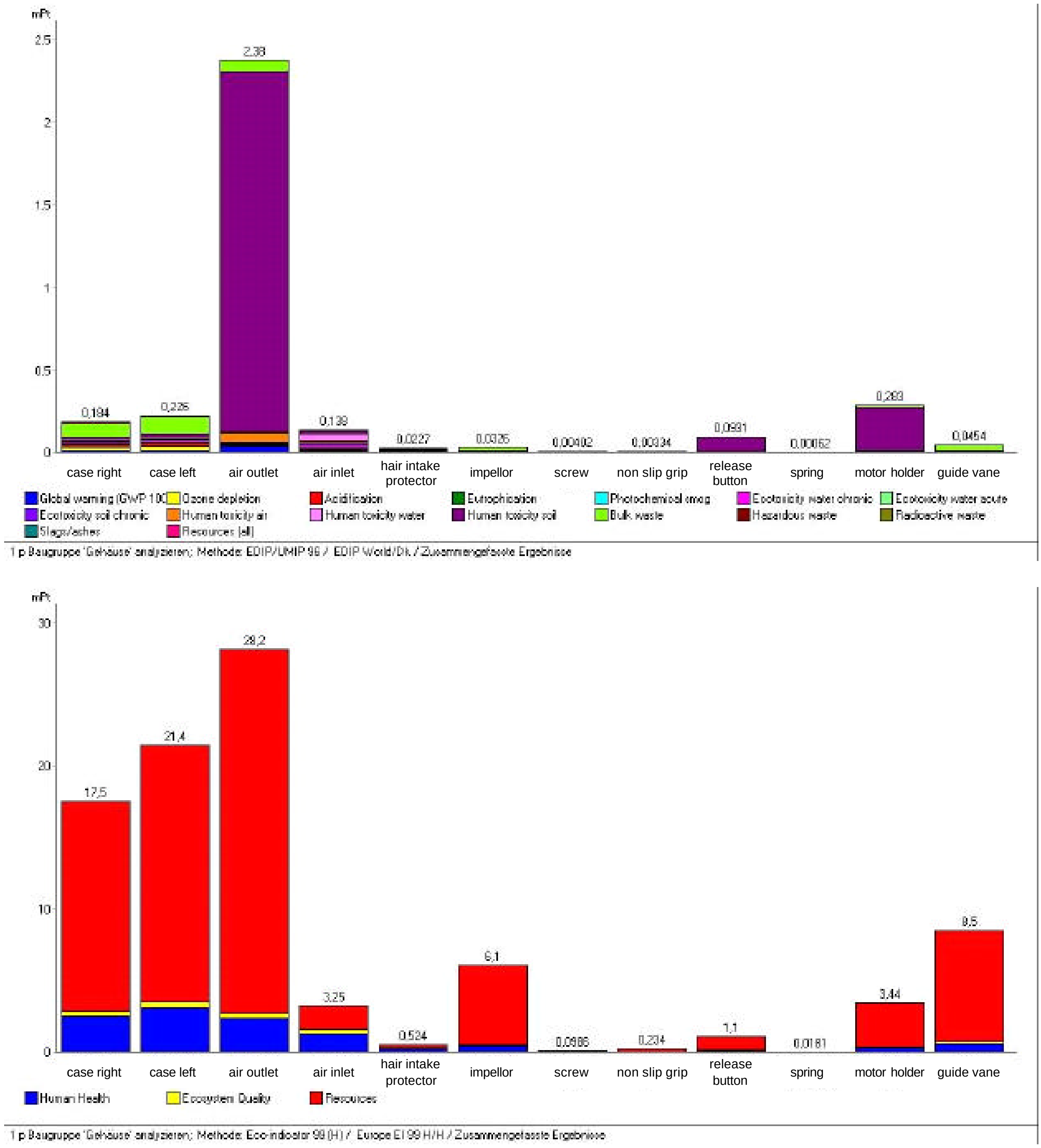

Figure 4. Indicator results of the assembly "housing" of a hair dryer using different impact assessment methods (EDIP/UMIP 96-upper picture; EI 99 (H)-lower picture)

These are just two examples, but the differences between the other methods are still confusing enough. More pictures of different products could be presented here, but the message would be the same => **There is no true environmental impact of any single part**. Of course the methods use different impact categories, grouping and weighting, so it is possible to trace back why the results are different. But what would the message be? The fact is that different impact assessment methods produce different aggregated results.

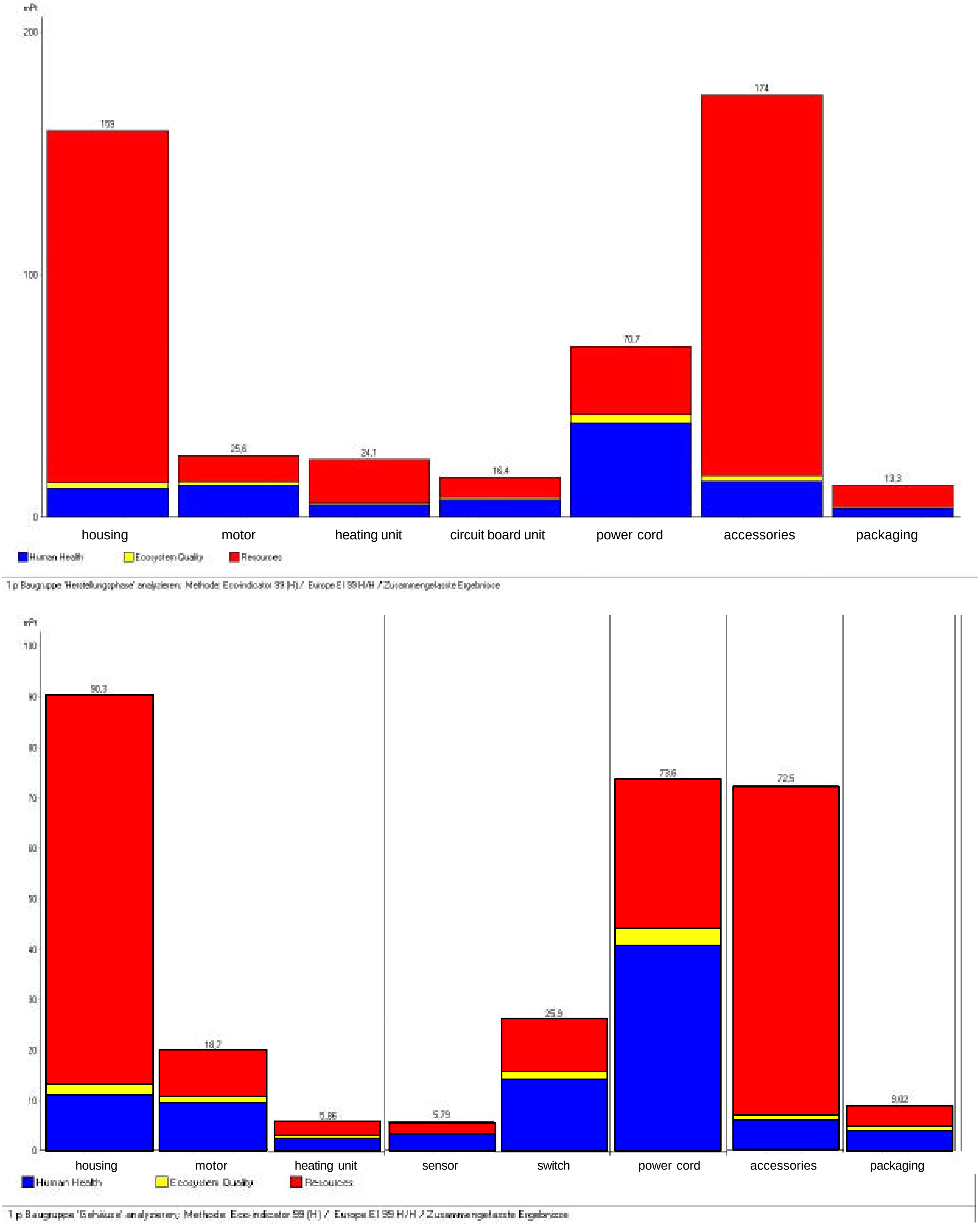

Figure 5. Indicator results of the production phase of two hair dryers using the EI 99 (H) method

Of course this comparison is not completely fair since using different methods during a study is not allowed, but it shows that environmental impact assessment is, in the end, a fact of value-choices and "good will". What happens if the assemblies of different products are compared using one method? In Figure 5 the production of two hair dryers is compared.

From this picture a comparison of the different parts can be made and requirements concluded. But keeping the above results in mind leaves one doubting if the parts (net cable and housing) with the highest impact according to EI 99 (H) method are ultimately those with the highest impact? As shown before, it might be that different methods reveal different parts. So, one answer to the question "which part has the highest environmental impact?" is not possible. So why care and what to do?

Carrying out an LCA at least tells the product developer where to start and what to consider. Every method, e.g. points out the use phase as the life cycle phase with the highest environmental impact (Figure 6).

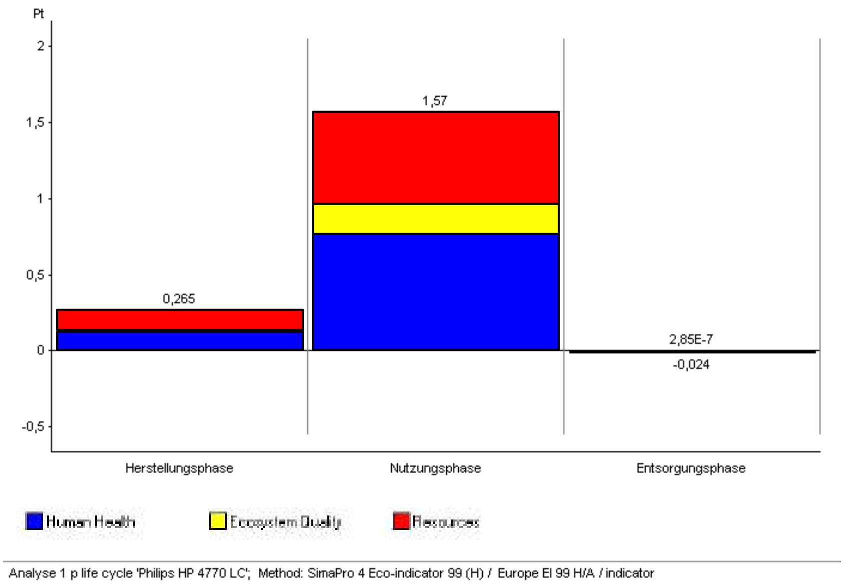

Figure 6. Indicator results of the life cycle phases of a hair dryer using the EI 99 (H) method

After lessening the environmental impact during the use phase, it is less important if the product developer first improves the housing or the accessories since both improvements are good for the environment. It is also not possible to answer the question by how much percent the parts are improved, since different impact assessment methods reveal different results. In addition to the different results with different methods, the above mentioned problems occur and many assumptions must be made. On top of this, much effort must be carried out to do a full LCA. It is therefore suggested to simply carry out an assessment using the ready-made Eco-Indicator scores provided by PRé Consultants BV [1] or IdeMat [2] during product development; in this case, the LCI and LCIA processes are dealt within one step.

4 Eco-indicator 99 scores

The scores of the Eco-indicator 99 tables are based on a full LCA and are, therefore, not only input-oriented, like CED [4] or MIPS [5]. As an example, the above mentioned citrus presses are used. Assessing the environmental impact of the citrus presses using ready-made Eco Indicators 99 gives the results shown in Figure 7. From these results it can be seen that, as not initially suspected, the electrical is better than the manual citrus press. This is mainly due to the higher juice yield of the electrical citrus press. Therefore, fewer oranges must be transported in order to fulfill the function unit (Assumption: Oranges are transported from Spain to Germany: distance Valencia – Frankfurt: 1600 km; impacts of the transportation in the use phase are shaded gray).

So the product developer sees now that it is best to raise the efficiency of the citrus press before optimizing the materials during production or the energy consumption during the use phase. This result can be drawn from a simple EI ’99 assessment using existing scores. Further evaluations reveal that the ABS and the copper used in the electrical press also cause most of the impact by the materials.

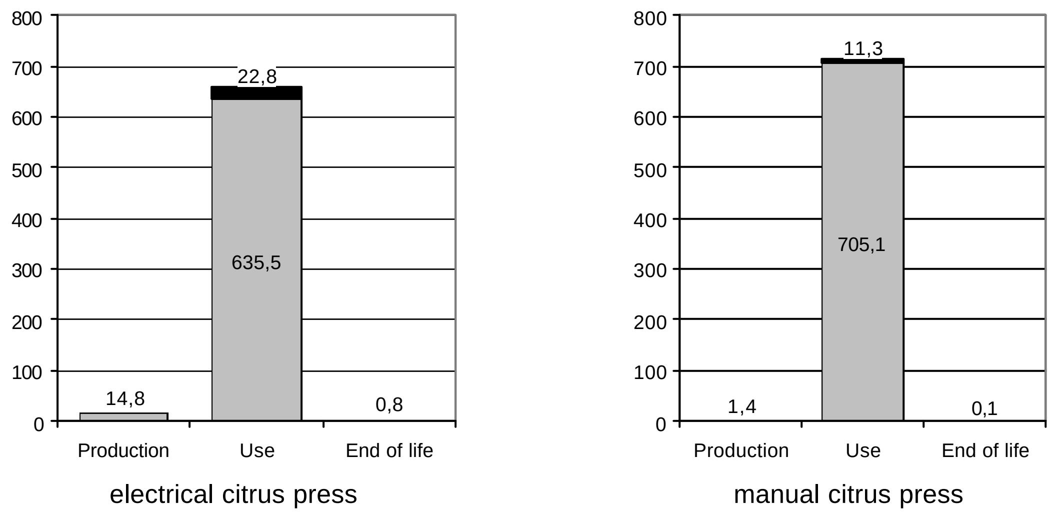

Figure 7. Environmental assessment using ready made EI 99 scores provided by [1] and [2]

5 Suggested Procedure

This simple example of the citrus press shows that it is necessary to carry out some kind of environmental impact assessment and that ready-made Eco-indicator 99 scores are often sufficient to identify relevant materials and processes during product development.

On one hand, assumptions have a high impact on the results of an environmental impact assessment, e.g. in the case of the citrus presses, the transportation distance and the amount of oranges necessary (the juice outcome of oranges varies over the season and the region of origin). Therefore, a thorough goal and scope definition is crucial for the validity of an environmental impact assessment. For the goal definition it is advisable to limit the environmental impact assessment to a comparative assertion (e.g. neglect the coffee beans in case of the coffee makers) which is closed to the public (only used in product development), so that the effort for carrying out the inventory analysis and the impact assessment is reduced.

On the other hand, the effort for a meticulous collection of inventory data is sometimes not proportional to the environmental impacts, especially taking the above mentioned problems, limitations and assumptions into account. Therefore, the authors suggest using existing Eco-indicator ’99 scores which are based on previously carried out LCAs. If an indicator score is missing, the practitioner should first check existing data bases to see if the inventory data have already been ascertained by a third party. But the practitioner must pay attention to the quality of the data before blindly using them (it is also advisable to use one data supplier since the data varies largely). If no third party inventory data can be found, co-operative projects with research institutes or universities are helpful, since inventory data collections are in many cases too complex and time-consuming for a company to carry out alone. In a second step, these inventory data are used to calculate a new Eco-indicator score using SimaPro 5.0 and the method Eco-indicator ’99 version **H**ierarchist/**A**verage.

Of course Eco-indicator ’99 is just one impact assessment method, and if desired, different impact assessment methods (on the condition that it is possible to aggregate the results to a single score) and different software can be used. But since there is no one true answer, why not take the easiest way? There are many existing Eco indicators scores in [1] and [2].

But never forget: Carrying out a sensitive analysis is necessary in order to **get a feel for the range of environmental impacts, especially for the effect of the** assumptions and uncertainties!

6 Conclusion

As can be seen from the examples, it is not always necessary to carry out a full LCA. In many cases, using ready-made Eco-indicator scores in product development is enough to identify relevant materials and processes, so that the LCI and LCIA processes are dealt with in one blow. Nevertheless, no general procedure can be suggested and, in some cases (e.g. for new materials or process, detailed assessment information, developing customized checklists) a full LCA must be carried out. The practitioner must carefully define the goal and scope of the environmental impact assessment in order to decide how to handle the given task. Nevertheless, always keep in mind that certain assumptions have a higher impact than the meticulous carrying out of the inventory analysis; therefore, it is important to always perform a sensitive analysis!

Acknowledgments

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