A Comparison between the Environmental Effect Analysis (EEA) and the Life Cycle Assessment (LCA) methods – Based on Four Case Studies.

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Abstract: This paper presents the results from a comparison between the Environmental Effect Analysis (EEA) and the Life Cycle Assessment (LCA) methods, both based on a life cycle perspective. The comparison is based on four case studies carried out by the authors in cooperation with Swedish enterprises. The basic materials to this paper are from four independent LCA studies carried out for four different products; limestone flooring, combustion of sawdust for district heating, refuse collection vehicle and powder coatings.

The major methodical difference between EEA and LCA is that EEA is using qualitative data while LCA is relying on quantitative data. Our case studies illustrate the differences and similarities between the methods. EEA can be used as an efficient method in the early phases of the design process. Thanks to the limited time needed to perform an EEA, rapid feedback of the results from an EEA into the early phases of the design process may be obtained.

Keywords: Environmental Effect Analysis (EEA), Life Cycle Assessment (LCA), Design for Environment (DfE)

1 INTRODUCTION

Design for Environment (DfE) is becoming more and more important for enterprises. The reason is that the consumer of today puts increasing demands on product environmental performance, particularly for capital goods as, for example, washing machines and cars. These demands have made the environmental aspects increasingly important in the product design process.

Environmental requirements, economic restrictions and technical feasibility [1] must be integrated into the design process, translated and transformed in such a way that the environmental demands can be accounted for and evaluated together with the rest of the design parameters [2].

In order to structure and facilitate this work a number of methods for Design for Environment (DfE) have been developed. Most of these methods are based on a life cycle perspective. The ‘life cycle’ is defined as all phases of the product existence from raw material procurement to end disposal, compare figure 1.

Unfortunately, many developers of tools for life cycle studies have failed to consider the organizational context in which tools are to be embedded [4]. The analytical methods must fit into how people work and interact and into the general design process.

![Figure 1. The life cycle can be divided into three major phases, production, use and end of life treatment [3].](image-url)
is realistically available in short product development cycles [5].

Furthermore, in the beginning of the design process knowledge about the product is limited. The information accessible is in general only qualitative. Many methods require quantitative data, something available only in the later phases of the design process. This hampers the successful application of life cycle studies. Obviously, it is important to get the results as early as possible in the design process before the modification cost becomes prohibitive and the freedom of action becomes too limited. Figure 2 shows the principal relation between freedom of action, product knowledge and modification cost. The figure is a further development of three figures, the design process paradox [6], costs allocated early but used late in the project [7] and the cost for design changes as a function of time during the planning and production process [8].

When a new design project is begun, very little is known about the final product, especially if the product is a new one for the designer. As work on the product is progressing, the knowledge is increasing and at the same time the freedom of action is decreasing since time and cost drive most projects. Costs for later changes increase rapidly, since earlier work has to be redone.

Figure 2. The principal relation between freedom of action, product knowledge and modification cost.

2 AIM AND SCOPE

This paper describes two DfE methods, Life Cycle Assessment (LCA) and Environmental Effect Analysis (EEA), both with a life cycle perspective.

Four case studies were evaluated with LCA and EEA respectively. The methods were compared regarding usefulness, time consumption and final result. Advantages and drawbacks of the two methods will be discussed.

3 MATERIALS AND METHODS

The basic materials to this paper are from four independent LCA studies carried out for four different products; limestone flooring [9], combustion of sawdust for district heating [10], refuse collection vehicle [11] and powder coatings [12]. The studies were originally performed by order from the enterprises themselves. The companies had different reasons to perform an LCA. Three wanted to know about their products’ environmental performance, advantages and disadvantages and one wanted to use the result from the LCA for marketing.

The LCAs were performed in close co-operation with the ordering enterprises. This made it quite easy to get specific data from their processes and products. In the study of the powder coating there was a major problem to get basic data from the raw material producers.

All basic data from the LCAs were saved and easy to reuse. The enterprises gave their permission to use the LCA data as long as we did not officially present secret or sensitive information.

Two major problems were faced. The first one was how to perform the EEAs. The enterprises did not have time involve themselves deeply. Furthermore, and most important, the companies were aware about the LCA results and could be influenced by them when performing the EEA.

The problems were solved by performing the EEAs and LCA independently. The researcher with the deepest knowledge and experience from EEAs performed this part of the study. He was also unaware of the results of the independently performed LCAs. For both types of studies the time for data extraction, processing and reporting were recorded.

4 LIFE CYCLE ASSESSMENT (LCA)

Today LCA is the most prominent tool used in DfE. It is a part of the ISO 14000 series. LCA is a technique for assessing the environmental aspects and potential impacts associated with a product. LCA studies the environmental aspects and potential impacts throughout a product’s life from raw material acquisition through production, use and disposal [13].

5 ENVIRONMENTAL EFFECT ANALYSIS (EEA)

The EEA method was primarily developed in 1996 by a Swedish consulting agency HRM/Ritline AB and has since been further developed in co-operation with other Swedish enterprises and Universities. The
method is a modification of the quality assurance method Failure Mode and Effect Analysis (FMEA). (Earlier the method was known as Environmental-FMEA, E-FMEA). The EEA method emphasizes environmental effects during normal operations unlike FMEA, which stresses potential failure risks [14].

EEA is used for the purpose of identifying and evaluating potential environmental impacts in all life-cycle phases of a product. The objective of the tool is to take corrective and preventive actions to minimize the environmental burden from products during their lifecycle.

5.1 The EEA procedure

Figure 3 shows the EEA methodology flow chart. An EEA is carried out by an EEA working team. The team shall represent different functions/parts of the product’s life cycle, e.g. project leader, purchasers, marketers, designers, environmental specialists, and service personnel. The participants should be involved in the current product design process.

The project leader of the product to be designed and manufactured should be the initiator of the EEA project and set up an EEA working team.

Important inputs for the EEA are earlier knowledge and identified environmental related requirements on the product. Environmental demands can be grouped into the three kinds: authority demands, market demands and internal demands.

An environmental expert should lead the EEA team.

The EEA form, figure 4, is the central part of this method. It enables the group to systematically assess each activity involved in the product’s life cycle.

The form comprises a number of columns. These columns are grouped into different areas; the first part identifies environmental characteristics, the second one ranks environmental aspects, and the third part describes which actions to take.

On the basis of the environmental requirements the form is filled in, step by step:

1. The first step is to identify the product’s/process’ life cycle phases and to identify all activities connected to the phase. Examples of activities are production, transportation and welding.

2. The next step is to find the environmental effects (green house effect, ozone depletion etc) of each activity.

3. The third step is to evaluate and grade the effects with regard to their environmental significance. The evaluation may vary from one organization to another depending on type of products, customers, supplier chain etc. In the column named Valuation, see figure 4, there are four subcolumns, each representing different criteria. The first three criteria are S = controlling documents, I = public image, A = environmental consequences. These criteria are graded from 1 to 3 depending on compliance from an environmental perspective. Adding these numbers creates the Environmental Priority Number (EPN) = S + I + A.

![Figure 3. EEA flow chart [14]](image-url)
An important factor is the improvement possibility (F), which focuses on the effort in time, cost and technical possibilities needed to environmentally improve a product or a part of a product. Improvement possibility is rated from 1 to 9, where 1 = no possibility to improve and 9 = very good possibility to improve.

4. The step after evaluation is recommended actions, see figure 4, column “Proposals for Action”. Different kinds of recommendations are listed and then decisions are taken, which in turn are analysed again to make sure environmental improvement is achieved. As shown in the matrix of figure 5, appropriate actions to be taken can vary depending on the environmental priority number and improvement possibility.

The matrix of figure 5 shall be used as an auxiliary, assisting tool. As an example, if in square B of figure 5 the product receives a high EPN and a high value of improvement possibility, then the product is not favourable from an environmental point of view and it can easily be improved. The recommended action is to keep the technical solution, but alter its content.

6 RESULTS

The major results from four different case studies are described in the following subchapters.

6.1 Limestone flooring [9]

Boulders from the quarry are treated in the factory by using big saws to produce thin slabs which are further refined in different grinding machines. Large amounts of limestone waste are produced in these processes.

It was quite easy to get data from the products life cycle except for the end of life treatment phase. The time needed to measure and collect the quantitative data was quite high.

Figure 6 shows, according to the LCA, the relation between the production, use and end of life treatment of the limestone. The major influence is from the quarrying of limestone boulders. A lot of energy, materials and time are wasted on boulders that are rejected in later phases of the production.

The EEA indicates three hot spots, visual impact from exploiting the limestone flooring at the quarry, energy consumption and emission to water of copper from the grinding.

Those hot spots could be diminished if the ratio between limestone quarrying and limestone used in products was shorter. Both the EEA and the LCA are pointing at the same problem, the lack of an efficient method to put energy, material and time on limestone boulders only that will give useful material in the end.
Figure 6. The normalized assessed environmental influence from the LCA. Four different LCA weighting methods very used to assess the inventory data (EPS, ECO S, ET long S and ET norm S).

6.2 Combustion of sawdust for district heating [10]

The sawdust used for district heating is a waste product from parquet producer Kährs AB located 30 kilometers from the district heating plant in Kalmar.

The focus in this case study was on the actual heat production. The district heating distribution system is outside the system boundaries.

The needed data for the EEA and LCA was in general quite easy to identify but the time needed to measure and collect the quantitative data was relatively high. It was hard to find specific data for the forestry and felling so data from other LCAs were used.

The conclusions of the LCA depend on whether the carbon dioxide from the sawdust is included or not. If carbon dioxide is included, the combustion in the district heating plant is responsible for almost 90 percent of the normalized assembled environmental influence. If not, the felling is responsible for almost 30 percent and different kinds of transportations for approximately 20 percent of the assessed environmental impact.

The EEA is carried out assuming that the carbon dioxide is included and the only identified hot spot is the disposal of wood ash. Today the ash is sent to the municipal landfill. The ash contains fertilizing substances such as Ca, K, Mg, P and S, that is, the substances that the trees during growth absorb from the ground.

From 1 of January 2000, there is a new disposal law for organic waste in Sweden. A fee of 250 SEK/ton deposited waste adds an economic incentive to recycling wood ash.

The EEA points out that the disposal fee is important. It is interesting because the LCA does not consider the ash as any big problem in comparison to the other assessed environmental impacts. The economic incitement is not included in the LCA.

Kalmar Energy has started a research project with the aim to recycle wood ash back to the forest ground. If it is possible to get pay for the wood ash as fertilizer, this could be a new business for the district heating plant.

6.3 Refuse collection vehicle [11]

Norba AB is manufacturing a set of standard waste units adaptable to ordinary lorries.

During recent years, Norba has spent much efforts on environmental improvements of their products. The company has focused on the production phase and is since five years certified according to ISO 14 001 and EMAS. Furthermore, it has decided to carry out an LCA and an EEA for all their products.

In general, it was easy to find data needed for the study. The focus in the data collection was on the manufacturing and use of the waste unit. The end of life treatment phase was not included in this study because of lack of data.

The result from the LCA was that 95% of the total normalized assessed weighted environmental impact is from the use of fossil fuel. The major way to decrease the impact is to reduce the weight of the waste units. The second most important improvement is to make the waste compaction process more energy efficient.

During production, the major assessed environmental impact is from the use of metal sheets for the waste container and other metallic parts. Norba has already today reduced their metal sheet use and is still trying to reduce it further.

The result from the EEA differs from the LCA in that the use of metal sheets is not identified as a hot spot. Hot spots in the EEA are the use of fossil fuel and the use of hydraulic oil during the employment of the waste units, the hazardous waste, and the emission of solvents during the production.
The recommended action to reduce the environmental impact would be to reduce the waste units weight and hence decrease the metal sheet consumption.

6.4 Powder coating [12]

The powder coating is a mix of several more or less secret substances, bought from raw material producers. At Herberts Powder Coatings plant in Västervik, the substances are mixed and processed into a powder. The mix depends on desired color and quality.

This case study covers a white powder coating for Electrolux refrigerators and freezers. At the Electrolux plant, the powder is applied on the surface of the Electrolux products and then put into an oven where the coating is transformed into a white surface.

In this study, it is assumed that the products with powder coatings are finally disposed of at Stena Bilfragmentering AB. In their fragmentation process the powder coating is separated from the rest and sent to landfill as hazard waste.

The data collection process and especially the inventory for quantitative data was very difficult and time consuming. In general, the big raw material producers refused to hand over any data at all with the justification that the data was a business secret. Even when the company management of Herberts made an inquiry for the data, they refused.

In this case study we had to use data from LCAs performed on similar substances. It was a major problem to find information about the substances used in the powder coating mix, especially quantified data. For a large number of substances representing a considerable fraction of the coating, we could not find any useful data at all.

The production phase and application phase are included. End of life treatment is excluded because of lack of data.

Approximately 80 percent of the assessed environmental impact is from the production phase. Figure 7 shows the relation expressed as a percentage between the different assessed steps.

It is easy to realize that the production of these substances would represent a larger part of the impact if more data were available.

The application of the powder coating requires a sizeable amount of energy and it represents almost 20 percent of the total environmental impact.

It was impossible to create an EEA on the production of raw material substances because of lack of data. The numbers from tables used in the LCA were useless. The numbers do not provide information on how the substance were produced.

![Figure 7. The normalized assessed environmental impact of the powder coating according to the LCA. Four different LCA weighting methods very used to assess the inventory data (EPS, ECO S, ET long S and ET norm S.](image)

The two most important hot spots identified in the EEA are the hazardous waste from the cleaning of the mixing machines at Herberts Powder Coatings plant in Västervik and the hazardous waste from the end of life treatment.

6.5 The time factor

Time needed for an EEA or an LCA can be discussed in two ways, the time needed for the actual work (working hours) and the time from project start to end.

Table 1 shows the working hours needed for each case study divided into each method. The time is estimated and not exactly measured.

<table>
<thead>
<tr>
<th>Case Study</th>
<th>EEA</th>
<th>LCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone flooring</td>
<td>40</td>
<td>230</td>
</tr>
<tr>
<td>Combustion of sawdust for district heating</td>
<td>30</td>
<td>180</td>
</tr>
<tr>
<td>Refuse collection vehicle</td>
<td>30</td>
<td>150</td>
</tr>
<tr>
<td>Powder coating</td>
<td>60</td>
<td>250</td>
</tr>
</tbody>
</table>

Table 1. The approximated time needed to collect data and complete each analysis.

One major reason to the big time differences is the extra time needed to measure, collect and quantify the data needed for the LCA. It was quite often hard or impossible to find useful data from the lifecycle. The
reasons were several e.g. suppliers rejected our data questions, was afraid to leave data about their process, or they did not have time or resources to collect data, the knowledge about the end of life treatment does not exist. Instead we had to find data from other sources, e.g. books, other LCAs and from similar processes or products.

The collection of quantitative data took quite along time. It was in general quite easy to get qualitative data needed for the EEA. This resulted in a longer time to conclude the data collection for the LCA than for the EEA.

EEA on different projects at HRM/Ritline AB, and with a similar scope as our four case studies, shows total working hours between 60 and 80 hours per project. This includes the total time for all the team members including the time needed for the EEA-leader. This was also the findings in our four case studies where the number of working hours and time needed to accomplish an LCA was significantly higher than for the EEA.

The time from project start to end was shorter in the EEA, because the data needed for the analysis was much less extensive than the data needed to accomplish the LCAs.

6.6 Assumptions and system boundaries

In the case studies, we had to make some assumptions because of lack of data and of economic and time limitations.

In principal, the system boundaries could be set equal for both the EEA and LCA. The data needed for the different methods differ so the system boundaries of respective EEA and LCA are not totally identical in these case studies. All system boundaries were chosen in close co-operation with people who know the processes.

One reason why the system boundaries in some cases differ is the fact that we could not find any quantitative data for the LCA but it was possible to find qualitative data.

If it is impossible to find even useful quantitative data this is noted as a question mark in an EEA. The question mark point out that further investigation is needed to clarify the question mark.

7 DISCUSSION

The LCA and EEA methods differ in some major aspects e.g. LCA needs quantitative data in contrast to EEA that needs qualitative data. It is easier to find qualitative data and the industry is in general less restrictive to hand over that kind of information. Qualitative data is also in general more informative and easier to understand than quantified data.

The time needed for the inventory to find quantified data is very long and costly in terms of working hours. As a result, the time needed for the LCA in general exceeds the time for the design process. The result arrives to late too be useful in the design process.

One major problem with LCA is that it does not include the preferences of the customer, something also emphasized by Luttropp [15]. The producers must always consider customer demands. The environmental aspect is just one of many.

The case studies illustrate that the LCA and the EEA focus on different aspects. The LCA analyses the product environmental impact but it does not indicate if it is feasible to reduce the impact. An EEA on the other hand focuses on whether it is possible to reduce detrimental effects and their relative importance.

To be useful in the design process the methods must give some kind of guidance to the users. Our experience is that the users of the EEA, emphasize the importance of product improvement. Where the LCA is a map of the environmental impact of a product, the EEA points out the road to improvement possibilities.

Sherwin and Bhamra [16] criticize LCA usage for being too narrow, focusing on products and limiting analysis to an existing product. Accordingly, innovative approaches are not supported by the use of LCA.

To make more and precise conclusions, it is necessary to make additional and more elaborate case studies.

One disadvantage with the EEA is the easiness to misuse the method. The evaluation is in a way subjective and therefore is it very important to describe how the work has been accomplished. Because of the use of qualitative data and the subjective evaluation the results from an EEA should not be used for marketing.

8 CONCLUSIONS

The time needed to accomplish an EEA is less than for an LCA. Furthermore the EEA does not need quantitative data, something that is important if the method is to be used in the design process according to figure 2.
The LCA is too limited in describing environmental impacts and it should not be used in the design process. LCA does not provide necessary support from a design and business perspective. This conclusion has also been mentioned by Brezet et al. [17].

The disadvantage with the EEA method is that it can be considered as a too subjective method if it is wrongly used.

In conclusion, EEA can be used as a method in the early phases of the design process. Thanks to the limited time needed to collect data and perform an EEA, the result from EEA can be transformed into the early phases of the design process. Many enterprises in Sweden have realised that benefit and are now successfully using the method.

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10 REFERENCES