LCA Methodology

Evaluation of Two Simplified Life Cycle Assessment Methods

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Abstract

Goal, Scope and Background. Two methods of simplified LCA were evaluated and compared to the results of a quantitative LCA. These are the Environmentally responsible product assessment matrix developed by Graedel and Allenby and the MECO-method developed in Denmark.

Methods. We used these in a case study and compared the results with the results from a quantitative LCA. The evaluation also included other criteria, such as the field of application and the level of arbitrariness.

Results and Discussion. The MECO-method has some positive qualities compared to the Environmentally responsible product assessment matrix. Examples of this are that it generates information complementary to the quantitative LCA and provides the possibility to consider quantitative information when such is available. Some of the drawbacks with the Environmentally responsible product assessment matrix are that it does not include the whole lifecycle and that it allows some arbitrariness.

Conclusions. Our study shows that a simplified and semi-quantitative LCA (such as the MECO-method) can provide information that is complementary to a quantitative LCA. In this case the method generates more information on toxic substances and other impacts, than the quantitative LCA. We suggest that a simplified LCA can be used both as a pre-study to a quantitative LCA and as a parallel assessment, which is used together with the quantitative LCA in the interpretation.

Recommendations and Outlook. A general problem with qualitative analyses is how to compare different aspects. Life cycle assessments are comparative. The lack of a quantitative dimension hinders the comparison and can thereby hinder the usefulness of the qualitative method. There are different approaches suggested to semiquantify simplified methods in order to make quantitative comparisons possible. We think that the use of fabricated scoring systems should be avoided. If quantitative information is needed, one should consider performing a simplified quantitative LCA instead.

Keywords: Electric cars; ERPA-matrix (ERPA: Environmentally Responsible Product Assessment); life cycle assessment (LCA); MECO-method (MECO: Materials, Energy, Chemicals and Others); semi-quantitative LCA; simplified LCA; streamlined LCA

Introduction

A complete, quantitative LCA has never been accomplished, nor is it likely to be (Graedel 1998). It could therefore be practical to start with less detailed studies and work towards more detailed studies (Lindfors et al. 1995).

There are three basic levels of LCA (Wenzel 1998):

- a matrix LCA; qualitative or semi-quantitative,
- a screening LCA; quantitative using readily available data or semi-quantitative,
- a full LCA; quantitative and including new data inventory.

The quality and quantity of the information to support a decision increases gradually in these levels.

Differences between quantitative and qualitative LCA are like points on a continuum (Todd and Curran 1999). It is not possible to quantify everything, so qualitative data and estimations are therefore necessary to create a comprehensive picture even in a quantitative LCA. It is also possible to consider quantitative information in a qualitative LCA, when such is easily accessible.

A simplified LCA is as a simplified variety of detailed LCA conducted according to guidelines not in full compliance with the ISO 1404X standards and representative of studies typically requiring from 1 to 20 person-days of work (Guinée et al. 2001). It can be qualitative, quantitative or semi-quantitative. A large number of simplified LCA-methods have been developed, see for example reviews in Christiansen (1997), Graedel (1998), Todd and Curran (1999) and Johansson et al. (2001). Different approaches for streamlining quantitative LCAs have been evaluated (Lindfors et al. 1995, Hunt et al. 1998). The fields of application for simplified LCA-methods are, for example, product development and procurement. Many of these methods are developed for a specific group of products and are not well documented. (The terms 'simplified' and 'streamlined' are here used as synonyms, in line with earlier publications, e.g. Christiansen 1997).

Since a full LCA can be time and resource consuming, there is a need for using simplified methods. However, it is important to evaluate simplified methods and to study what type of information they can produce. We tested two simplified semi-quantitative LCA-methods, the Environmentally responsible product assessment matrix (here called the ERPA method) (Graedel and Allenby 1995) and MECO (Wenzel 1998, Pommer et al. 2001). These methods were chosen since they are well documented and fundamentally different. The purpose of this study was to evaluate these methods and to discuss the usefulness of simplified LCA-methods. The study forms part of a larger project concerning environmental considerations in the acquisition of defence material.

1 Method

1.1 Study method

Two simplified LCA-methods (MECO and ERPA) were tested on a case study of electric cars and cars with combustion fuel. Fundamental data for the test were collected from a published, quantitative LCA (Almemark 1999) and from a database of fuel (Uppenberg et al. 1999). The analyses with MECO and ERPA were made independently to each other and without knowledge of the results from the published LCA. The same person, who started with the ERPA-method, carried out the analyses. The products analyzed were the driveline (the transmission system), the fuel tank, the catalyst and the fuel in petrol and ethanol cars; the driveline, battery and electricity production for the electric cars. Hereafter, we use the term 'car' to mean the driveline, fuel tank and the catalyst or driveline and battery. All data are based on use of the cars in Sweden during a period with an air temperature of +20°C. The electric cars had a nickel-cadmium battery and an estimated life length of 175 000 km. The life time distance for both the petrol car and the ethanol car was 150 000 km.

We compared the cars with each other according to the following:

- The electric car driven on electricity from water power (E.w.) and the electric car driven on electricity from coal (E.c.),
- The petrol car (P) and the ethanol car (E),
- The electric car driven on electricity from water power and the petrol car.

After carrying out the analyses using the two methods, we evaluated them by comparing the results from the methods with each other and with the published quantitative LCA (Almemark et al. 1999). We also used the following questions as guidance for the evaluation. The questions were chosen, in order to illustrate interesting characteristics of the methods.

- Is it possible to include qualitative information in the analysis, when using the method?
- Is it possible to include toxicity in the analysis, when using the method?
- Is land use in the analysis, when using the method?
- Is production of consumables in the analysis, when using the method?
- Does the method use any weighting method resulting in one single score as a result?
- Is it easy to use the method?
- What is the approximate time required doing the analysis?
- How large is the extent of arbitrariness within the method?
- What is the method intended for?
- How flexible is the method? Can it be adjusted to the needs of the user?
- When using the method, how do the results differ between the methods and from the quantitative LCA?

1.2 The environmentally responsible product assessment matrix

Graedel and Allenby have developed a method for semi-quantitative LCA at AT&T (see for example Graedel and Allenby 1995, Graedel 1996, Graedel 1998). This method has been used in several case studies, see for example Graedel (1997), Graedel and Nakaniwa (2002) and Graedel and Saxton (2002). The abbreviation ERPA is used in this paper to describe the method.

The central feature of the assessment is a 5x5 matrix (**Table 1**). One dimension is the life cycle stages and the other is environmental concern. The method can be used to evaluate products, processes, facilities, services or infrastructure. We used the application for products described in Graedel (1998). Each element of the matrix is assigned a rating from 0 (highest impact) to 4 (lowest impact), according to a checklist. It should be noted that the rating is based on the seriousness but also on whether possibilities of reducing impacts have been utilized or not (Johansson et al. 2001). One example is the checklist for matrix element 4,5 (Graedel 1998):

If the following condition applies, the matrix element rating is 0:

- Product generates significant quantities of hazardous/toxic gaseous residue during use or from repair/maintenance operations

If the following condition applies, the matrix element rating is 4:

- Product generates no (or relatively minor amounts of) gaseous residues during use from repair/maintenance operations.

If neither of the preceding ratings is assigned, complete the checklist below. Assign a rating of 1, 2 or 3 depending on the degree to which the product meets the Design for Environment (DFE) preferences for this matrix element.

- Has the periodic emission of gaseous materials (such as CO_2, SO_2, VOCs, and CFCs) associated with the use and/or maintenance of this product been avoided or minimized?
- Have alternatives to the use of gaseous consumables been thoroughly investigated and implemented where appropriate?
- If intentional dissipative emissions to air occur as a result of using this product, have less environmentally harmful alternatives been investigated?
- If the product contains any gaseous materials that have the potential to be unintentionally dissipated during use or repair, have the appropriate preventive measures been incorporated?

A product's total environmental responsibility (R_{erp})is calculated as the sum of the matrix element values (M_{ij}):

$$R_{erp} = \sum_i \sum_j M_{ij} \quad [1]$$

This addition implies that all cells in the matrix are given the same weighting, irrespective of the importance of each life cycle stage or environmental stressor for the analysed product in its entirety. Graedel (1998) has developed a method to weight the matrix by consensus. The life stages that are likely to produce the most severe environmental impacts are chosen and arbitrarily weighted higher than the other stages. The same can be done for a dominating environmentally related attribute. Graedel (1998) has also developed a method for considering time, distance, risk and exposure in the analysis.

Table 1: The environmentally responsible product assessment matrix (Graedel 1998)

Life cycle stage	Materials choice	Energy use	Solid residues	Liquid residues	Gaseous residues
Premanufacture	1.1	1.2	1.3	1.4	1.5
Product Manufacture	2.1	2.2	2.3	2.4	2.5
Product Delivery	3.1	3.2	3.3	3.4	3.5
Product Use	4.1	4.2	4.3	4.4	4.5
Refurbishment, Recycling, Disposal	5.1	5.2	5.3	5.4	5.5

Table 2: MECO chart (Pommer et al. 2001)

	Material	Manufacture	Use	Disposal	Transport
1. Materials a) quantity b) resource					
2. Energy a) primary b) resource					
3. Chemicals					
4. Others					

1.3 MECO

The Danish Institute for Product Development and dk-TEKNIK have developed the MECO principle in co-operation with a larger Danish project. The use of the principle is described in 'Handbook for Environmental Assessment of Products' (Pommer et al. 2001), which is intended for small and medium-sized companies. The principle divides the assessment into four areas in accordance with the underlying causes of the product's environmental impacts. These areas, which have given the principle its name, are Materials, Energy, Chemicals and Others (Wenzel et al. 1997).

The information on the studied product/ system is first structured in the MECO chart (**Table 2**). The analysis with the chart can be followed by a more detailed LCA, making a gradual evaluation of the product.

All inflows and outflows must be considered for one category at a time based upon the functional unit and the chosen life cycle phase.

The category 'Material' includes all the materials needed to produce, use and maintain the product. Materials that are being reused in the phase of disposal are entered in the Disposal box, marked with a minus sign. The use of materials is partly presented as quantity (1a) and partly as resources (1b).

The category 'Energy' includes all energy used during the product's life cycle, including the use of energy during the supply of materials. The use of energy should be indicated as primary energy (2a) and as use of oil resources (2b).

To be able to compare products, the use of material and energy should be calculated as consumption of resources, in millipersonreserve (mPR). One personreserve is resource consumption in proportion to the global reserves of a resource, available for one person and all future posterity. The use of energy is calculated as use of oil resources.

The category 'Chemicals' includes all chemicals in the product's life cycle. The chemicals are classified as type 1, 2, or 3 according to their environmental hazard level. Type 1 refers to very problematic substances, type 2 problematic and type 3 less problematic substances. The classification was made with help from EU directives on marking of chemicals (EU directive 67/548/EEG, European Commission 1967) and Danish lists (Listen over farlige stoffer, Effekliste, Listen over uønskede stoffer, Miljøstyrelsen 2000a,b,c). A chemical is classified as type 1, 2 or 3 depending on whether it is within both, either, or neither of these lists.

Environmental impacts that do not fit into the categories described above should be included in the category 'Other'.

1.4 The quantitative LCA

Results for the quantitative LCA were taken from Almemark et al. (1999). Their work can be described as a fairly typical LCA-study performed in Sweden during the late 1990s. The study basically followed ISO-standards and the Nordic guidelines (Lindfors et al. 1995). It included an impact assessment but no weighting element.

2 Results from the Analyses

2.1 Results from the ERPA-method

Table 3 shows the results from the analyses with the ERPA-method.

Table 3: The environmentally responsible product assessment matrix

Life cycle stage	Materials choice	Energy use	Solid residues	Liquid residues	Gaseous residues
Premanufacture	**P:** 2 **E:** 2 **E.w:** 2 **E.c:** 2	**P:** 2 **E:** 2 **E.w:** 2 **E.c:** 2	**P:** 2 **E:** 2 **E.w:** 2 **E.c:** 2	**P:** 2 **E:** 2 **E.w:** 2 **E.c:** 2	**P:** 2 **E:** 2 **E.w:** 2 **E.c:** 2
Product Manufacture	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data
Product Delivery	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data
Product Use	**P:** 0 **E:** 2 **E.w:** 4 **E.c:** 4	**P:** 0 **E:** 0 **E.w:** 2 **E.c:** 2	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P:** 0 **E:** 0 **E.w:** 4 **E.c:** 4
Refurbishment, Recycling, Disposal	**P:** 2 **E:** 2 **E.w:** 1 **E.c:** 1	**P, E:** No data **E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P, E, E.w, E.c:** No data	**P, E:** No data **E.w:** 2 **E.c:** 2

P= Car driven on petrol, **E=** Car driven on ethanol, **E.w:** Car driven on electricity from water power, **E.c:** Car driven on electricity from coal.
P: 12/36, **E.c, E.w:** 23/40, **E:**14/36

The checklists for Product Manufacture, Product Delivery and most parts of Refurbishment contain many questions on the processes of the stages, which we were unable to answer, due to lack of sufficient information. Most parts of the remaining elements were given the grade 2. This depended on the difficulties of assigning the elements a fair grade with respect to the checklists. Detailed explanations for the scores are presented in Hochschorner et al. (2002).

According to the ERPA-method, there were no differences between the two electric cars. The reason of this is that no consideration is given to the production of the consumables according to this method. This means that the production of petrol, ethanol and electricity was not included in the studied system.

The differences between the petrol car and the ethanol car arise during product use; the choice of material (fuel) in the ethanol car is less hazardous to the environment than in the petrol car.

The comparison of the electric car driven on electricity from water power and the petrol car gave the following results: The electric car had smaller amounts of gaseous residues and less use of energy and materials in the Product Use stage than the petrol car. The disadvantages with the electric car are the choice of material in the life cycle stage of Refurbishment, Recycling and Disposal.

2.2 Results from the MECO-method

Table 4 shows the results from the analyses with the MECO model. Only the main differences between the cars are shown in the matrix. A question mark indicates that calculations were not possible for some of the substances. More details concerning the results are presented in Hochschorner et al. (2002).

We did not have enough data to evaluate the impact of materials during the phases Manufacture, Use and Transport and the impact from chemicals during the phases Manufacture and Transport.

Table 4: MECO-matrix

	1. Materials	2. Manufacture	3. Use	4. Disposal	5. Transport
1. Materials a) quantity (kg)	Substance differences: **P, E:** porcelain, Rh, Pl **E.c**, **E.w**: PVC, Ni, Cd, Co	**P, E, E.c**, **E.w**: No data	**P, E, E.c**, **E.w**: No data	**P, E, E.c**, **E.w**: No data concerning use of materials **E.c**, **E.w**: products from recycling: Cd:–21 kg Ferro-nickel scrap: –58 kg	**P, E, E.c**, **E.w**: No data
b) resource (PR)	**P, E**: 0.3 **E.c**, **E.w**: ? + 180 PR			**E.c**, **E.w**: Cd: –90 Ferro-nickel scrap: ?	
Sum (PR)	**P, E:** 0.3 **E.c**, **E.w**: 90				
2. Energy a) primary (GJ)	**P, E:** ? + 12 **E.c**, **E.w**: ? + 34	**P, E:** ? + 4 **E.c**, **E.w**: 5	**P:** 420, **E:** 510 **E.c**, **E.w**: 380	**P, E:** ? + 3 **E.c**, **E.w**: 7	**P, E:** 0.2 **E.c**, **E.w**: 0.6
b) resource (PR)	**P, E:** ? + 12 x 10^{-3} **E.c**, **E.w**: ? + 33 x 10^{-3}	**P, E:** ? + 4 x 10^{-3} **E.c**, **E.w**: 5 x 10^{-3}	**P**:0.4 **E**:0.5 **E.c**, **E.w**: 0.4	**P, E:** ? + 3 x 10^{-3} **E.c**, **E.w**: 7 x 10^{-3}	**P, E:** 0.2 x 10^{-3} **E.c**, **E.w**: 0.6 x 10^{-3}
Sum (PR)	**P:** 0.4 **E:** 0.5 **E.c**, **E.w**: 0.4				
3. Chemicals	Substance differences: **P, E:** porcelain, Rh (class 2), Pl (class 2) **E.c**, **E.w**: PVC, Ni (class 1), Cd (class 1), Co (class 1) For the content of chemicals in each car, see Tables 6 and 7	**P, E, E.c**, **E.w:** No data	**P:** Petrol (class 1) **E:** Ethanol (class 3) For emissions during the fuel cycle, see Table 5	**P, E, E.c**, **E.w**: Data missing regarding use of chemicals **E.c**, **E.w**: Emissions from the recycling process of 100 kg batteries: 60 mg Cd (air) 0.04 mg Cd (water) 0.2 mg Ni (air) 0.2 mg Ni (water)	**P, E, E.c**, **E.w**: No data
4. Others		**P, E, E.c**, **E.w**: Primary material for generation of European electricity-mix	**P, E, E.c**, **E.w**: Environmental pollution from generation of petrol, ethanol, electricity from water power and electricity from coal, respectively	**P, E, E.c**, **E.w**: The process of recycling	**P, E, E.c**, **E.w**: Primary material for generation of European electricity-mix

P= Car driven on petrol, **E=** Car driven on ethanol, **E.w:** Car driven on electricity from water power, **E.c:** Car driven on electricity from coal.
A question mark indicates that calculations were not possible for some of the substances

Differences between the two electric cars arise in the generation of electricity: commandeering of large areas for generation of water power versus extraction of coal. The type and amounts of emissions from generation of electricity from coal are different than those from water power. This aspect can be considered under the category 'Others' (matrix element 4.3 in Table 4).

Differences in the generation of fuel also appear in the comparison of the petrol car and the ethanol car. Cultivation of grain for production of ethanol generates different environmental impacts than generation of petrol. Other differences between the cars are that ethanol is a type 3 chemical and petrol a type 1 chemical (matrix element 3.3 in Table 4). The ethanol generates lower emissions of SO_x, NMVOC, CO_2 and higher emissions of NO_x, CO, N_2O and particles during the whole fuel cycle compared to the petrol used in the petrol car (**Table 5**).

The results from the MECO model indicate that the electric car driven on electricity from coal consumes more material and energy in the supply of materials (matrix element 1.1 and 2.1, in Table 4) and more energy in the stages of Disposal and Transport (matrix element 2.4 and 2.5 in Table 4) than the petrol car. The electricity from coal generates more emissions of SO_x, CH_4 and particles, and fewer emissions of NO_x, CO, NMVOC and N_2O during the whole fuel cycle than the petrol used in the petrol car (Table 5).

Table 5: Emissions during the whole fuel cycle

Emissions (kg)	Electricity from coal	Petrol	Ethanol	Electricity from water power
NO_x	15	29	50	Data missing
SO_x	24	13	6	
CO	14	77	163	
NMVOC	0.7	30	15	
CO_2	32,000	34,000	9,200	
N_2O	0.5	8	14	
CH_4	380	4	3	
Particles	9	2	27	
NH_3	0.8	–	–	

The data indicate total environmental impact during the whole fuel cycle (Uppenberg et al. 1999) calculated for the life-length of each car. Data concerning electricity from water power are missing in Uppenberg et al.

The classifications of all chemicals encountered for the different cars are presented in **Table 6** and the amounts of chemicals used for each car in **Table 7**. As can be noted in Table 7, the electric cars contain more type 1 substances

Table 6: Chemicals in the stages materials, use and disposal

Substance			Evaluation			
Name	CAS-No	Usage	Classification	Effektlisten 2000	Listen over uønskede stoffer	Type
ABS plastic	9003-56-9	Material in the car	No classification			2
Aluminium (powder)	7429-90-5	Material in the car	F; R15- 17			2
Petrol	86290-81-5	Fuel	Carc.2; R45 Xn; R65	X		1
Ethanol	64-17-5	Fuel	F;R11			3
Rubber (nature ~)	68425-13-8	Material in the car	No classification			2
Hydroxides		Material in the car	No classification			2
Cadmium	7440-43-9	Emissions from the recycling of the batteries, Material in the car	N; R50-53		X	1
Cobalt	7440-48-4	Material in the car	R42/43	X		1
Carbon dioxide	124-38-9	Emissions when driving the car	No classification			2
Carbon monoxide	630-08-0	Emissions when driving the car	F+; R12, Repr.1; R61, T; R23-48/23	X		1
Copper	7440-50-8	Material in the car	No classification		X	1
Nitric oxides	10102-44-0	Emissions when driving the car	T+; R26 C; R34			2
Methane	74-82-8	Emissions when driving the car	F+; R12			3
Nickel	7440-02-0	Emissions from the recycling of the batteries, Material in the car	Carc.3; R40 R43	X	X	1
Platinum	7440-06-4	Material in the car	No classification			2
Polythene (PE)	9002-88-4	Material in the car	No classification			2
Polyvinyl chloride (PVC)	9002-86-2	Material in the car	No classification			2
Porcelain		Material in the car	No classification			2
Rhodium	7440-16-6	Material in the car	No classification			2
Steel (fibre)	7439-89-6	Material in the car	No classification			2
Sulphur dioxide	7446-09-5	Emissions when driving the car	T; R23 C; R34	X		1
Water	7732-18-5	Material in the car	No classification			–

The classification was made according to the N-CLASS Database on environmental Hazard Classification (Nordic Council of Ministers). This database is available on the Internet, see http://www.kemi.se. The subdivision into types was made according to Pommer et al. (2001) and is further described in Hochschorner et al. (2002)

Table 7: The amount of chemicals used in each car

Substance	Type	Chemicals in the electricity cars (kg)	Chemicals in the petrol car (kg)	Chemicals in the ethanol cars (kg)
Aluminium	2	58	36	36
Rubber	2	6		
Cadmium	1	40		
Cobalt	1	3		
Copper	1	14	5	5
Nickel	1	50		
PE	2	2	10	10
Plastics (assumption: ABS- plastic)	2	34	3	3
Platinum	2		1.5×10^{-3}	1.5×10^{-3}
PVC	2	1		
Rhodium	2		4.5×10^{-3}	4.5×10^{-3}
Steel	2	230	120	120
Petrol	1		9,880	2,550
Ethanol	3			14,950

The amounts of petrol and ethanol were calculated on the basis of the life cycle length for the cars

than the petrol or ethanol cars. However, the fuel in the petrol car is type 1. The petrol car used 10 000 kg petrol during the studied life-cycle.

2.3 Results from the quantitative LCA

The car driven on petrol was compared with the ethanol car and the electric car according to eight environmental impact categories (**Tables 8** and **9**) (Almemark et al. 1999). The electricity for the electric car was assumed to be produced from Swedish average electricity mix, mainly nuclear and hydropower.

A comparison could not be made between the two electric cars, since these cars were not part of the study.

The ethanol car has probably less use of fossil energy than the petrol car and has significantly less impact on the eutrophication and probably more impact on the acidification than the petrol car, according to Almemark et al. (1999).

The electric car driven on Swedish electricity mix has significantly less impact than the petrol car on the following environmental stressors: Global Warming Potential, use of fossil raw material and Photooxidant Creation (Almemark et al. 1999). On the other hand, the electric car has a significantly larger impact than the petrol car on the following environmental stressors: Use of natural resources and production of disposal (Almemark et al. 1999). The emissions to air from the electric car are probably less than from the petrol car, according to Almemark et al. (1999).

Table 9: The value of the impact category, as a multiple of the value of a petrol car (according to Almemark et al. 1999)

Impact Category		Symbol	Significance
Fossil energy GWP	<0.2 times	++	Significantly better
	<0.5 times	+	Probably better
	>5 times	– –	Significantly worse
The other categories	<0.1 times	++	Significantly better
	<0.2 times	+	Probably better
	>5 times	–	Probably worse
	>10 times	– –	Significantly worse
All categories	Out of the interval above	0	No significant change

Table 8: Fuel from Swedish electricity composition and Ethanol E85 compared to petrol

Fuel	Fossil energy	Natural resource	GWP[1]	AP[2]	EP[3]	POCP[4]	Disposal	Toxicity, air emissions
Electricity, Swedish composition (approximately 45% nuclear power, 47% hydropower)	++	– –	++	0	0	++	– –	+
Ethanol, E85	+	0	0 (+?)	–	– –	0	0	0 (–?)

The comparison is based on use of the cars when the outside air temperature is +20 degrees Celsius. The symbols represent different qualitative values, see Table 9 (Almemark et al. 1999)

[1]GWP, Global warming potential — [2]AP, Acidifying Potential — [3]EP, Eutrophying Potential — [4]POCP, Photo-oxidising Chemical Potential

3 Results from the Evaluation and Discussion

3.1 Results from the evaluation

The results from the evaluation are summarised in **Table 10**.

The results generated from the three methods provide us with different types of information. The quantitative LCA generates quantitative results from some, but not all, relevant impact potentials. Some toxic effects and effects caused by use of land are examples of excluded relevant impact categories. It can be noted that this is a fairly typical result for quantitative LCAs (Finnveden 2000).

The results from the MECO-method can be quantitative (primarily the use of energy and resources) or qualitative (chemicals or others). The chemicals in the product are given a preliminary prioritization in three different groups. All relevant information can be included in the matrix under the category Others. This method gives less information on some traditional impact categories and more information on toxic substances and other impacts, compared to the quantitative LCA used in this study.

The ERPA-method gives semi-quantitative information on the environmental stressors. The information can, in contrast to the MECO-method, be aggregated to one or a limited amount of numbers, if all matrix-elements are given the same weighting (or if modified weighting of the elements has been carried out.)

The results and conclusions drawn from the three methods are partly different. One of the conclusions from the quantitative LCA is that an electric car can give significant reductions in fossil fuels and CO_2-emissions depending on the production of the electricity used (Almemark et al. 1999). This sort of conclusion cannot be drawn from the ERPA-method, since the production of electricity is not included in the method. In spite of the calculation of energy as oil-equivalents in the MECO-model, such a conclusion could be drawn from the information under Other or from the data of emissions under Chemicals. We used emissions data from a fuel database (Uppenberg et al. 1999). These data illustrate the differences in air emissions generated from different methods of electricity production.

One of the disadvantages of the electric car is the use of resources for production of the batteries, according to the quantitative LCA (Almemark et al. 1999). This conclusion can be drawn from the MECO-matrix but not from the ERPA-matrix, where all four cars get the same grade in the stage Premanufacture. A third conclusion pointed out in the quantitative LCA is that the electric cars generate more solid residues than the two other cars. This conclusion cannot be drawn from either the MECO-matrix or the ERPA-matrix.

If the data in the ERPA-method are aggregated, the different cars can be placed in order of precedence. The electric cars are preferable to the ethanol car, which is preferable to the petrol car. Such an unambiguous aggregation is not made in MECO or in the quantitative LCA. One reason for this might be that the production of electricity, which is an important part of the lifecycle of the electric cars, is not included in ERPA.

Some of the results from the quantitative LCA are not included in the MECO-matrix or in the ERPA-matrix. It can, however, be noted that some information provided by the MECO-method is not included in the LCA or in the ERPA-matrix. The MECO-method and the quantitative LCA complement each other to some extent. The ERPA-method does not consider the whole lifecycle perspective, as the production of consumables (in this case fuel and electricity) is not included. This may lead to loss of important environmental aspects.

The time needed to perform a simplified LCA depends on the availability of the required information and on the user's experience. MECO requires information on materials and chemicals in the product. ERPA requires in addition information on performance of the processes during the product's life.

Table 10: Results from the evaluation

Criteria for the evaluation	MECO	SLCA	The quantitative LCA
Qualitative information	Yes, under Other	No, not in the matrix	No, not in this case
Toxicity	Yes	Yes	Yes, partly
Land use	Yes, qualitatively under Other	No	No, not in this case
Production of consumables	Yes	No	Yes
Weighting method	No	It is possible to get the results as an aggregated number for the product's environmental responsibility	No, not in this case
Easiness	Good. But, the lists limit the user	It depends on the background information	Requires LCA expertise
Time	It depends on the availability of information and the experience of the user. In this case 1-2 weeks for all four cars	It depends on the availability of information and the experience of the user. In this case 1–2 weeks for all four cars	Months
Extent of arbitrariness	Somewhat	Large	Somewhat
The intention of the method	Product development	Product development	Wide scope
Flexibility	Somewhat	Small	Somewhat
Results compared to the quantitative LCA	See text above and below	See text above and below	

3.2 Comments on the MECO-method

All energy used in the lifecycle phases should be calculated as consumption of oil resources, according to Pommer et al. (2001). This calculation implies that the energy resources actually used in the product's lifecycle phases are not considered. Those authors claim that this conversion makes it possible to compare the use of energy with the use of materials.

The characterization method used by Pommer et al. (2001) implies that the remaining reserves of a resource should be used as base for the weighting. The reserves are defined as known and profitable reserves. Other methods could be used (see for example Finnveden 1996 and Lindeijer et al. 2002 for a summary) which produce different results (for example Lindfors et al. 1995). A further development of the MECO-method can include a discussion on the appropriateness of the characterization method for resources.

Materials, energy and chemicals that are recycled/reused in the disposal phase should be included in the matrix, with a minus sign. This implies that the recycled (reused) amount is ascribed to the product that can use these materials, energy or chemicals. This is one possible solution for the so-called open-loop recycling allocation-problem (see for example Ekvall and Finnveden 2001). There are, however, other solutions that can give different results (e.g. Lindfors et al. 1995). In this case too, a further development of the MECO-method can include a discussion on the appropriateness of this methodological choice.

The classification of chemicals is partly based on Danish lists. An adaptation of the MECO-method to other countries could include the choice of other lists or criteria for the classification.

3.3 Comments on the ERPA-method

The grading in the ERPA-method allows some arbitrariness. The checklist for matrix element 4,5 (see above) can illustrate this. To assign the element a grade of 0 or 4, the user has to consider one condition. If neither of these conditions is right, the user assigns a rating of 1, 2 or 3 depending on the degree to which the product meets the DFE (Design for Environment) preferences for four questions. The grading depends on the operator, and may vary depending on who assigns the grades.

This can be illustrated by the comparison of our ERPA grading and that described by Graedel and Allenby (1998) in the book 'Industrial Ecology and the Automobile'. The gradings in Graedel and Allenby's matrix are from a general point of view higher than ours. One example is the element's Materials choice, Energy use and Gaseous residues under the Product Use. We grade these three elements 0, 0 and 0 (Table 3), while Graedel and Allenby grade them 1, 2 and 2.

Another example of the difficulty in assessing a fair rate is to decide how large is a significant quantity of residues. Is it in relation to similar products, to other residues from the product, or in relation to other residues in the area?

The aggregation is another example of arbitrariness. The grades can be aggregated, if all the elements are assumed to be equally important. Graedel (1998) describes a method to give some phases or environmental stressors a higher weighting. However, it is difficult to find a line of direction for when or how to do this and the allowance for arbitrariness is thereby large.

The questions in the ERPA-method require knowledge of the performance of the processes during the product's life cycle, for example product delivery and production processes. The operator has to know whether the processes are developed with regard to environmental considerations. This type of information is sometimes unknown for an assessor, as illustrated in Table 3. The ERPA-method is primarily developed for product development and it may be the case that this type of information is often more readily available inside a company. However, if the application is in procurement, it may be more difficult to find some of the information required by the ERPA-method.

Even if the product contains environmentally harmful substances, the matrix elements in question could get a high grade if there are no other suitable alternatives. If, for example, a toxic substance is used in the product and there are suitable alternatives available, the matrix element concerned will get a low grade. However, if no suitable alternatives are available, then the product will get a higher grade although the substance is still toxic.

The grading can help to decide which process should be improved, but it can also be misleading, since all categories get the same weighting. For example, the packing of the product is considered to be as important as the use of the product. This is not always the case.

The production of the consumables is not considered in the checklist. The only matrix element that slightly considers this is element 4,1, Product Use, Materials Choice, where the operator has to know whether the consumables contain significant quantities of materials in restricted supply or toxic/hazardous substances. Our analysis with the method did not show any differences between the cars driven on electricity from water power or from coal.

3.4 A discussion of streamlined LCA

Choosing a streamlined LCA-method involves a balance between the simplification of the method and the type of results the user is looking for. There is no method that is preferable over all others under all conditions.

However, there are situations when the user has to choose between different methods. The field of application should serve as guidance for that decision. When the method has to support a decision, it is important to know what type of information is needed to support such a decision and if the method can deliver this information (Todd and Curran 1999). It is also important to consider the type of streamlining. What is most relevant, to use a method that simplifies by excluding a dimension or one that simplifies by using already available data?

The criteria we used can be helpful in allowing the most suitable method to be chosen. By comparing the results from the methods with a quantitative LCA as a reference, we assumed that the quantitative LCA gives more reliable results.

Whether or not this is fair, however, could be discussed. Since all LCAs are streamlined in some way (e.g. Todd and Curran 1999), this would imply that the results from a less simplified method are more right than the results from a more simplified method. However, since a quantitative LCA is more comprehensive than a streamlined LCA, it can also contain more estimations than a streamlined LCA.

A general problem with qualitative analyses is how to compare different aspects. Life cycle assessments are comparative. The comparison is either with an alternative system, with a reference or internal within the analyzed system to identify important environmental aspects. The lack of a quantitative dimension hinders the comparison and can thereby hinder the usefulness of the qualitative method. On the other hand, problems in quantitative methods can arise when complex states are reduced to uncertain numbers that are used without nuances.

The difficulties in making comparisons can be more or less important depending on the application. A differentiation can be made between two extreme functions of LCA:

- To support a choice between two or several alternatives.
- To identify critical aspects and suggest mitigation strategies.

In practice, both these functions can be relevant for a specific case study, but the emphasis on the two functions can vary. It is much more important to have quantitative data for the first function than for the second function. This can be illustrated by an example. If we are comparing two products; Product A which includes the hazardous chemical X and product B which includes the hazardous chemical Y, then it is difficult to make a choice between products A and B if no quantitative information is available. If nothing is known either about the amounts used or the toxic properties of the chemicals, then it is very difficult to make a choice. On the other hand, if the aim is to identify a key issue and suggest mitigation measures, then it may be enough to identify the hazardous chemical and suggest either a change to a substance which is not classified as hazardous or a reduction in the amounts of the chemical used. In this case, the need for quantitative information is much reduced.

There are different approaches suggested to semiquantify simplified methods in order to make quantitative comparisons possible. This is done for example in the ERPA-method. We think that the use of fabricated scoring systems should be avoided (Johansson et al. 2000). The scoring system in the ERPA-method should instead be used as a checklist to identify critical aspects. If quantitative information is needed, one should consider performing a simplified quantitative LCA instead. Another solution is given in the MECO-method, where it is suggested that quantitative information be used if it is easily available and if so, a quantitative dimension can be added to the qualitative evaluation.

A potential problem using qualitative methods is that qualitatively, most products may turn out to be rather similar. It is the quantitative aspects that can differentiate between different products. For example, all products that in their lifecycle use energy from combustion processes (i.e. most products) will cause emissions of heavy metals and persistent organic pollutants. It is the quantitative aspects that differentiate between different products, i.e. how much energy is used and how large emissions of heavy metals and persistent organic pollutants are caused by the different products. Since the quantitative dimension is lacking in a purely qualitative evaluation, it may be difficult to differentiate between different products.

In all quantitative LCA, there are aspects that are difficult to quantify and that therefore must be handled qualitatively. Experience shows that this qualitative information often gets little attention when results are presented and conclusions drawn. It may therefore be a good idea to perform a formal qualitative assessment if it can help capturing and illuminating qualitative information that is difficult to quantify. If that is possible, then a qualitative and a quantitative assessment can complement each other. This was illustrated above, where the results from the quantitative LCA and the MECO-method partly complemented each other.

In **Fig. 1**, a possible simple LCA procedure is illustrated where the simplified LCA, in this case a MECO-assessment possibly complemented by an illustrative process-tree, can be used both as a pre-study to a quantitative LCA and as a complementing study to the quantitative LCA.

Simplified methods can be useful in several applications, e.g. product development and procurement. Different methods may be more or less suitable for different applications. In procurement, one application for simplified methods is to identify critical aspects of products. Once they have been identified criteria for procurement can be established (Hochschorner and Finnveden 2003).

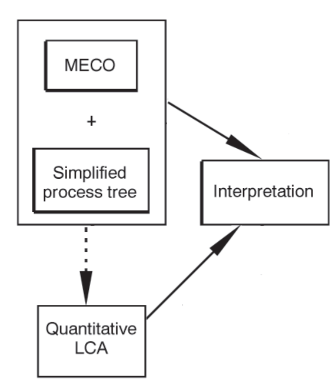

Fig.1: A suggested simple LCA procedure

4 Conclusions

In a comparison of two streamlined LCA-methods, two of the most important criteria are the field of application and whether the method can deliver the required information. Other criteria that can be helpful in choosing the most suitable method are those used in our study.

The ERPA-method has some drawbacks as illustrated here. Some of its shortcomings are that it does not include the whole lifecycle, that it requires a lot of information that in some cases are difficult to find and that it allows some arbitrariness.

The MECO-method has some positive qualities compared to the ERPA-method. Examples of this are that it generates information complementary to the quantitative LCA and provides the possibility to consider quantitative information when such is available. It seems reasonable to focus on material inflows early in the process, since information on these is easier to access than information on emissions. Furthermore, it also seems reasonable to focus on energy and chemicals with the use of energy as an indicator for several environmental impacts. Since a simplified and semi-qualitative LCA (such as the MECO-method) can provide information that is complementary to a quantitative LCA, a simple procedure is suggested where a simplified LCA is used both as a pre-study to a quantitative LCA and as a complementary assessment, which is used together with the quantitative LCA in the interpretation.

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