LCA and Eco-Design Education Programme

Two Fictional Life Cycle Assessments

Exercise Book

Edited by Bo Pedersen Weidema

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A COMETT II PROJECT

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Preface

This book has been produced to complement the text book "*Environmental Assessment of Products*", but can also be used independently. The purpose of this book is to introduce the practical design and evaluation of the life cycle assessment, not how to execute the actual data collection.

This book is published within the framework of the LCA and Eco-Design Education Programme, which is a COMETT II-project coordinated by the University Enterprise Training Partnership in Environmental Engineering Education, UETP-EEE hosted by the Finnish Association of Graduate Engineers TEK.

The book is planned to be used in workshops and practical exercises in training courses and higher education for engineers, environmental managers and other prospective life cycle assessment practitioners.

The best way to learn about life cycle assessments is to perform one. However, the task of producing or evaluating a real life cycle assessment study tends to be rather complicated and time consuming. "Learning by discovery" is a way to introduce life cycle assessment using carefully created fictional samples which emphasise the critical aspects of the life cycle assessment process. Given the task of making a critical "peer review" of the reports, the reader will discover the mistakes deliberately built-in and see how these affect the conclusions of the reports. The fictional reports contain all the information needed for evaluating them. In some of the cases, the best information can be found by combining parts of both reports. To make the use of the book easy, we have included worksheets containing questions that the student should answer based on the information presented in the two example reports. Also an example answer in a form of a short peer-review is included. It is recommended to first answer the questions in the work sheets and make your own peer-review, before reading this chapter.

It is also good to remember, that this is not the only possible answer, maybe not even the best.

Chapters 7 and 8 are aimed at teachers, and describe the use of the book as an educational material.

I

Fictional LCA reports – excercises

1 Introducing the baby napkin studies

The two fictional life cycle assessments are very similar in that:

- they are performed for the same institution (Storeby County, Denmark) at the same time (May 1993) with the same purpose (to compare two specific existing systems for baby napkins in day nurseries),
- they are to a large extent based on the same data sources.

One can imagine that the County has asked for the same task to be performed independently by two consultants (perhaps knowing that the task is so difficult that it is interesting to see two independent results).

As can be easily seen (even from the summaries of each report) the two reports reach contradictory conclusions. One report recommends the disposable napkin system, the other recommends the reusable napkin system.

The reason for this difference in the conclusions can be found in the way the two consultants *interpret* the task and in their more or less explicit choices of *methodology*.

The quality of the reports also differs. On some points one report gives more explicit descriptions than the other, on other points opposite. The manner in which the two reports present the data and calculations are also very different.

There are no (intentional) errors in the presented data and calculations as such; the only differences in the reports are in their methodological choices (functional unit of product, system boundaries etc.) and in a few cases differences in the data sources. Together, the two reports contain all the data necessary to redo the calculations made. Thus, in a longer course, the students may be asked to take the best methodology and the best data from each report and make a completely new report for which they must calculate the result themselves. For the calculations it will be an advantage to have access to a computer. At present the data on the baby napkin case may be obtained with the following software:

- *SimaPro*, obtainable from Pré, Bergstraat 6, NL-3811 NH Amersfoort, The Netherlands; telefax: (+31) 33 611 046,
- *PLA Educational Tool with LifeWay*, obtainable from Visionik Aps, Vendersgade 29 st.tv., DK-1363 København K., Denmark; telefax: (+45) 3313 4240.

Obviously, the data may be entered manually in any other professional software. *SimaPro* also have a data export format.

Not all the data and references are real. Any resemblance between fictional enterprises mentioned in the reports and actual enterprises is unintentional. Please do not use the data for any purpose outside the educational context for which they have been prepared.

2 Work sheets – questions

The following work sheets may be used during the group sessions or for self-tuition. One work sheet has been prepared for each of the 5 sessions of the three-day course described in section 2 of this manual:

- 1st session: Objectives, product definition, choice of alternatives and process trees.
- 2nd session: System boundaries.
- 3nd session: Aggregation, evaluation and presentation.
- 4th session: Data quality.
- 5th session: Sensitivity analysis.

If time allows, it may be advantageous to let the students produce their own checklists based on chapters 4 and 5 of the textbook "*Environmental assessment of products*" rather than use the pre-produced work sheets.

It is important that the questions are not answered mechanically (yes/no), but that the reports are actually criticised and suggestions for improvement given.

Work sheet 1.

"Produce a critical peer review of the two reports. List the positive and negative aspects in each report and make suggestions for improvements"

Sections on objectives, product definition, choice of alternatives and process trees.

Is the intended use of the study clearly stated?
Are the limitations of its use for other purposes clearly stated?
Are the geographical and temporal limitations of the result stated?

Are the organisation(s) and person(s) financing the study stated?
Are the organisation(s) and person(s) participating in the study mentioned?

Is the functional unit of product clearly defined and in accordance with the objectives of the study?

Have any product alternatives been excluded which could reasonably be regarded as relevant alternatives?
Are the arguments for the selection of product alternatives explicitly stated?
Are the arguments for the selection of product alternatives consistent with the objectives of the study?

If time allows, discuss the way the functional unit specifies the material flow for the two product systems (look in the reports immediately after the flow charts).

Work sheet 2.

"Produce a critical peer review of the two reports. List the positive and negative aspects in each report and make suggestions for improvements"

The system boundaries of the two product systems (life cycles).

Are any processes or parameters omitted and if so have appropriate arguments been given to justify this?

Have the data (especially for energy) been collected from the appropriate geographical areas and for the appropriate technological levels in accordance with the objectives of the study?

Are products which may reasonably be regarded as complementary products included in the analysis and if not, has an argument been made to justify their exclusion, based on a sensitivity analysis?

Is the allocation method for multi-output processes stated (e.g. for agricultural products) and is it reported that the chosen method is appropriate?

Work sheet 3.

"Produce a critical peer review of the two reports. List the positive and negative aspects in each report and make suggestions for improvements"

Aggregation, evaluation and presentation.

Is the possible bias in the adding and aggregating of data into a total figure for the product system explicitly stated?

Are any supplementary procedures used (e.g. normalisation, exposure assessments etc.) which may give the result a specific bias?

Are value judgements and expressions of relative weights explicitly stated?

Have adequate arguments or sources been given for the value judgements and expressions of relative weights?

Does the conclusion and summary give a fair representation of the obtained result and its limitations, clearly and solely based on the data and methodology used and reported in the rest of the study?

Work sheet 4.

"Produce a critical peer review of the two reports. List the positive and negative aspects in each report and make suggestions for improvements"

Data quality.

Are all processes clearly defined by function and inputs and outputs (raw materials, energy use and products) with adequate quality specifications (e.g. water content, inherent energy)?

Is energy consumption stated explicitly and divided into electrical and direct thermal energy for each process and for the entire product systems, with relevant transformation coefficients when the energy is traced back to primary energy?

Are the transport distances and modes of conveyance reported between each process in the product system with specific adjustment factors for transport at non-ambient temperature and transport of lightweight products?

Are environmental data listed for each process and energy related data listed separately from process related data?

Are all data indexed with their source?

Is relevant information included on data quality?

Is the data quality (age, representativeness, reliability etc.) adequate to support the conclusions?

Is a clear statement given of the implications for the result of low data quality and possible missing data?

Work sheet 5.

"Produce a critical peer review of the two reports. List the positive and negative aspects in each report and make suggestions for improvements"

Sensitivity analysis.

Is uncertainty reported for all data?

Are the procedures used for sensitivity analysis clearly stated?

Are results of sensitivity analyses on key assumptions presented?

3 Example report 1

Comparison of the environmental effects of two baby napkin systems

by Elsie A. Masters
Masters & Co. Ltd.
Cambridge, U.K.

June 1993

3.1 Summary

This study is a comparison of the environmental effects of two existing systems for baby napkins: The disposable paper napkin Carefree from Barth AG, Kiel and the reusable cotton napkin service system BleService operated by the company BabyBackup, Storeby. The purpose of the study is to determine which of the two systems have the least environmental impact taking into account all effects in the life cycle of the products.

The study is specific to the two mentioned products and is, to the widest extent possible, based on enterprise-specific data and assumptions specifically related to the investigated systems. Therefore the conclusion should not be used for any other napkin systems.

The study concludes that the paper napkin system has the lowest consumption of fossil fuel and drinking water resources, and the lowest emissions of CO_2 and SO_2. The BleService system does not have comparable advantages. The Carefree napkin is therefore recommended. Lowering the COD-emission from the pulp production would give further advantages to the paper napkin. The uncertainty on this conclusion is very low (<5%).

3.2 Objectives and target group

This study is a comparison of the environmental effects of two existing systems for baby napkins: The disposable paper napkin Carefree from Barth AG and the reusable cotton napkin service system BleService operated by the company BabyBackup.

The study has been carried out in May 1993 by Elsie A. Masters of Masters & Co., Cambridge for Storeby County, Denmark as part of an effort to

reduce the environmental impact of the activities of the County. The County uses napkins in their day nurseries.

The purpose of the study is to determine which of the two available systems for baby napkins have the least environmental impact taking into account the entire life cycle of the products.

The purpose of the study has *not* been to suggest improvements in either of the two systems, although the report does contain information which may be used to identify parts of the two systems contributing most to the overall environmental effects. However, no investigations have been made into the possibility and feasibility of improvements.

The study has been made on the two systems as they appear today, without regard for future changes or other options. Thus, it is possible that the inclusion of other napkin service systems or other brands of disposable napkins would lead to a different conclusion.

The study has been performed specifically for use in Storeby County and therefore has limited applicability to other geographical conditions. Thus, the conclusions of this report should only be used to choose between the two investigated systems as they appear today in Storeby County.

3.3 Financial involvement

The study is financed by an EC regional grant administered by Storeby Council.

3.4 Product definition and product alternatives included

The products to be compared are the disposable paper napkin Carefree from Barth AG, Kiel and the reusable cotton napkin service system BleService, operated by the company BabyBackup. BleService is a rental system in which the users (child care centres and individual families) rent a specially designed cotton napkin which is delivered and collected twice weekly by BabyBackup, Storeby (once weekly for individual families).

The two mentioned alternatives are regarded as the only alternatives realistic for Storeby County. It has been considered to include other disposable paper napkins but this has been rejected for financial reasons, since Carefree is the cheapest napkin on the market. It has been considered to include ordinary reusable cotton napkins without the accompanying collection, washing and delivery service. However, this would imply that the employees at the day nurseries would have to do the washing, which has not been regarded as an acceptable (comparable) alternative to the disposable paper napkins (Garde 1993).

The product unit to be compared can be defined as:

> "the number of napkins necessary for comfortable and hygienic treatment of one average child until the age of 2.5 years."

No correlation has been found between the type of napkin used and skin irritation (Nylander 1991). The two napkin systems are therefore regarded as equivalent in this respect.

The age of 2.5 years is regarded as the average "napkin period" (Nylander 1991, Bast & Diehl 1990, and Franklin Associates Ltd. 1990).

In their comparative study for the American Paper Institute, Franklin Associates Ltd. (1990, p.2-7) use a number of 9.7 cloth napkins per day based on "data from various sources (which) were quite consistent" while

estimating a figure of 5.4 changes of disposable paper napkins based on the total sold amount of paper diapers multiplied by the market share (85%) divided by the number of children in the "napkin period".

In her study for the paper diaper producer Mölnlycke, Nylander (1991) uses the figures of 5 changes per day for disposable diapers in the first 2 years and twice a day in the last half year totalling 4000 changes. She estimates that one extra daily change is necessary for cloth diapers.

Based on both market estimates and interviews, the independent study of Bast & Diehl (1990) reaches a figure of 5567 napkin changes for paper napkins with a high estimate of 6000. For cloth diapers they use 7000 napkin changes.

Our own investigation shows that BabyBackup delivers 60 clean napkins weekly to a family with a child up to 4 months old, 35 napkins until the age of 12 months and thereafter 25 napkins per week per child. If these figures are corrected with three extra napkins per day (disposable napkins are supposed to be used when the child is handed over to the day care institution which perform also two changes) it gives the figures: 11 napkins per day in 4 months, 7.4 napkins per day in 8 months and 6 napkins per day in 18 months, which gives an average of 7 napkins per day or a total of 6400 changes in 2.5 years.

The results of the different investigations are summarised in table 1.

Table 1. Different estimates of the number of napkin changes per child

	Franklin Associates Ltd. (1990)	Nylander (1991)	Bast & Diehl (1990)	Own estimates
Disposable	4900	4015	5567	(5300)
Re-usable	8850	4900	7000	6400

In a comparative study, the interesting figure is not so much the actual number of changes but rather the difference between the two systems. There seems to be a general agreement that re-usable napkins demand more frequent change. The ratio between re-usable napkin changes and disposable napkins is 1.8 in the American study and 1.2 in the European studies. We use the latter ratio together with our own estimates of 6400 re-usable napkin changes which are thus compared to 5300 disposable napkin changes.

We estimate the widest difference between the two systems to be 2 extra napkin changes per day, since it is unlikely that the two products would be regarded by the consumer to be comparable if the difference was higher. This implies an estimated uncertainty of 10% on the ratio between the two systems giving a wide difference of 5050 to 6550 napkin changes and a narrow difference between the two systems of 5550 to 6150.

Franklin Associates Ltd. (1990) calculates the lifetime of re-usable napkins washed at home to be 180 washes, based on an estimated purchase of 48 napkins per child and an average napkin change rate of 9.7 per day. Bast & Diehl (1990) makes a similar calculation based on a purchase of 50 napkins for the first child in a family and an additional purchase of 20 napkins for the following children, 7000 napkin changes per child and a (German) distribution of child-families of 30% with one child, 43% with two children and 27 with more than two children. The resulting figure is 191 washes per napkin (our calculation). Nylander (1991) estimates a purchase of 35 napkins per child. Neither of these studies considers the possibility that napkins may be passed on from one family to another, an event that we regard as very common. On average, we estimate that this may lead to an extra 20-40 washes per napkin. Based on market statistics showing a figure of 78 uses per napkin in napkin service systems, a 70/30 ratio between reusable napkins sold in retail and to diaper services and a 13/87 ratio between diapers washed by napkin service systems and in private homes, Lehrburger et al. (1991) calculate the lifetime for privately washed napkins as 78 x

30/13 = 180 washes. However, the correct calculation using a trippage rate calculation would be 1 + (87 x 30 x (78 - 1))/(13 x 70) = 222 washes. In conclusion, we estimate the lifetime of a reusable napkin to be at least 220 washes.

However, the lifetime of reusable napkins in a service system is normally shorter than the lifetime of napkins washed at home. This is mainly due to the need of the service system to deliver an optically clean product (Parents are more willing to accept spots on the napkins if they know that the spot has been made by their own child).

Surveys of napkin service systems in U.S.A. indicate that napkins in a service system are withdrawn after between 50 (Franklin Associates Ltd. 1990) and 78 washes (Lehrburger et al. 1991) indicating a withdrawal of 2% and 1.3% respectively of the napkins per wash.

To improve the lifetime of their napkins, BabyBackup remove spots from the napkins with sodium hypochlorite (4% chlorine). This treatment is necessary in about 4 % of the napkin washes. Due to this treatment, the lifetime of the reusable cotton napkin is estimated by BabyBackup to be 150 changes. It has not been possible to verify this estimate, since the BleService system has not been in operation long enough to measure the actual lifetime. However, 150 changes being the average of the 78 indicated by Lehrburger et al. and the 220 estimated for private napkins, we regard the estimate as reasonable with an uncertainty of +/- 50%.

3.4.1 Complementary products

The reusable cotton napkin is used together with a pair of plastic lined cotton trousers also delivered by BabyBackup. One pair of trousers is estimated to last for 6400 napkin changes.

3.4.2 Limitations in life cycle

The weight of the above mentioned cotton trousers is 48 g. Thus, the material requirement for the trousers is negligible compared to that of the cotton napkins (4600 g; see below).

Beside energy consumption, the environmental effects of forestry and agriculture has not been included in the analysis, since they are regarded to be negligible (forestry) or of no consequence to the conclusion of the study (agriculture).

Capital equipment has not been included in the analysis, since our experience has shown its contribution to be negligible (<1%) for bulk products (such as pulp, paper and textiles).

3.5 The life cycle of the paper napkin "Carefree"

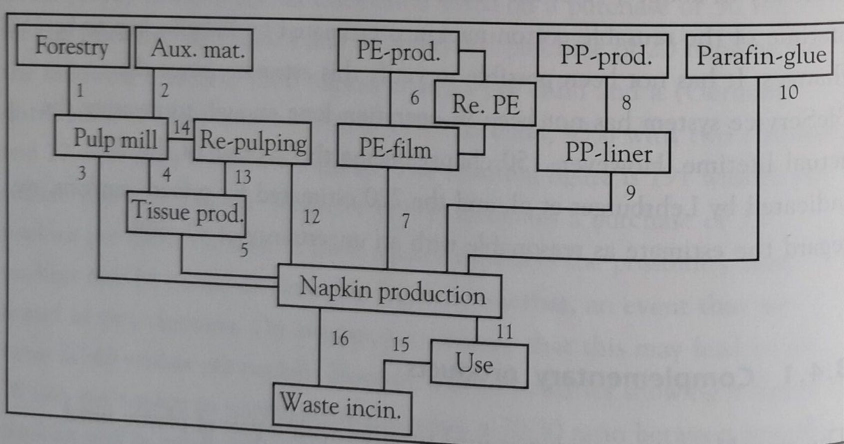

Figure 1. Flow chart for Carefree paper napkin.

3.5.1 Material flow

The paper napkin Carefree is found in several sizes to suit children of different age and sex. The weights, prices and relative market shares of the different sizes are as follows:

	weight per. napkin	market share
Carefree newborn:	41 g	22 %
Carefree medium:	55 g	28 %
Carefree maxi:	70 g	50%

From these figures, the average weight of a paper napkin can be calculated to 59.4 g.

Since the relative composition of the different napkins is approximately the same, the average composition is calculated from the maxi size (which has by far the largest market share). According to product information sheets from Barth AG Carefree maxi consists of:

Fluff pulp:	49 g
Paper tissue:	5 g
PP-lining:	5 g
PE-foil:	5 g
Paraffin-glue:	6 g
Total weight:	70 g

The uncertainty on this information is estimated to be low, i.e. +/- 5%. The composition has been roughly verified by approximate measurement of each component.

Carefree maxi is delivered in packs of 64 napkins in a PE-foil (measured weight 80 g, i.e. approximately 1 g per napkin).

To adjust for the difference in market shares of the different sizes, the above figures are multiplied with a factor 59.4/70 = 0.85 giving the following total figures per napkin including packaging:

Fluff pulp:	42 g
Paper tissue:	4 g
PP-lining:	4 g
PE-foil:	5 g
Paraffin-glue:	5 g
Total weight:	60 g

Barth AG estimates an average waste of 10% in the production, of which the paper waste is reused by the paper mills and the rest goes to municipal incineration.

If these wastes are included, the total material requirements per napkin are:

Fluff pulp:	46.2 g
Paper tissue:	4.4 g
PP-liner:	4.4 g
PE-foil:	5.5 g
Paraffin-glue:	5.5 g

The uncertainty on this information is estimated to be +/- 10%.

The material flow related to 5300 changes of Carefree can therefore be calculated as follows (numbers in italics refer to figure 1):

Pulp:	
Fluff pulp for napkins *(3)*	(46.2 g x 5300) 245 kg
Pulp for tissue paper *(4+5)*	(4.4 g x 5300 + 1 kg waste in tissue prod.) 24 kg
Waste fluff pulp *(12)*	(10% of 245 kg) -24 kg
Waste tissue paper *(13+14)*	-1 kg
Net amount of pulp	244 kg

for which is needed:

Wood *(1)*1.24 cubic metres (5.1 m^3 / t pulp) or	1265 kg
Auxiliary materials for pulp *(2)*	(155 kg / t pulp) 38 kg
Oil derivatives:	
PE *(6+7)*	(5.5 g x 5300) 29 kg
PP *(8+9)*	(4.4 g x 5300) 23 kg
Paraffin glue *(10)*	(5.5 g x 5300) 29 kg
Use:	
Napkins incl. packaging *(11)*	(60 g x 5300) 318 kg
Waste treatment:	
Used napkins *(15)*	(318 kg + 51 g urine and stool x 5300) 588 kg
Industrial waste *(16)*	(10% waste in napkin production) 7 kg

3.5.2 Energy supply

Table 2. Energy supply per 5300 Carefree napkins

	Diesel (MJ)	Electricity (kWh)	Gas and oil (MJ)
Forestry[1]	416	5.9	
Auxiliary materials for pulp prod.[2]		64.6	
Pulp production[3]		63.8	
Tissue production[4]		25.4	156
PE-production[5]		81.2	2291
PE-film production[1]		24.9	
PE-recycling[1]		0.8	
PP-production[5]		43.7	1679
PP-liner production[6]		28.8	
Paraffin-glue production[7]			1450
Napkin production[8]		50.0	
Repulping of paper waste[1]		6.8	
Total	416	395.9	5576

1 handbook data from 1984 (Tillman et al. 1991)
2 enterprise specific estimates (Österdal 1993)
3 Österdal 1993, including 700 km rail transport (Tillman et al. 1991)
4 handbook data without indication of age (Dogdale 1985)
5 industry averages (Boustead 1993a)
6 industry averages (Kindler & Nikles 1980)
7 average value for refined oil products from Boustead (1993b) probably underestimated
8 enterprise specific data (Schneider 1993) including 300 km rail transport (Tillman et al. 1991)
Uncertainty is estimated to be 10% on enterprise specific data (Österdal and Schneider), 25% on recent industry averages (Boustead) and 50% on other data.

3.5.3 Recovered energy

The used napkins are incinerated at Storeby municipal waste incinerator, which delivers district heating to industries and apartment buildings in Storeby (Garde 1993). To calculate the heat of combustion, an efficiency of 75% (including loss in transmission) and the following calorific values have been used (Tillman et al. 1991):

Paper products:	16.7 MJ/kg x 46 g = 0.8 MJ per napkin
Plastics and paraffin:	43MJ/kg x 14 g = 0.6 MJ per napkin
Water evaporation:	-2.3 MJ/kg x 44 g = -0.1 MJ per napkin
Total:	1.3 MJ per napkin x .75% efficiency = 1 MJ heat

The 44 g moisture is from urine and stool and has been calculated from Vert (1980) assuming an average of 5.8 napkin changes per day, (equivalent to 5300 changes in 2.5 years) giving figures of 34 ml of urine with 5% dry matter and 17 g stool with 30% dry matter.

The uncertainty on the data for recovered energy is estimated to be +/- 25%.

3.5.4 Emissions

Table 3. Emissions per 5300 Carefree napkins

	CO	CO_2	COD	Dust	HC	N, aq	NO_x	P, aq.	SO_2
	g	kg	g	g	g	g	g	g	g
Pulp prod.	7747[3]	0	8300[2]	195[1]	775[3]	34[2]	488[2]	3[2]	22[1]
Tissue prod.[1]	1	10	0	2	1	0	23	0	31
PE-prod.[5]	26	36	44	87	609	1	348	<0.2	261
PP-prod.[5]	16	25	9	46	299	1	230	<0.5	253
Paraffin-glue production[6]	2	8	<0.4	10	84	<0.2	84	<0.1	52
Waste incineration[1]	4240	233	0	4876	424	0	1166	0	127
Diesel combustion[1]	125	33	2	42	87	0	542	0	64
Electricity production[7]	57	52	0	24	1	0	164	0	306
Total	12214	397	8355	5282	2280	36	3045	4	1116

1 Tillman et al. 1991
2 Österdal 1993
3 calculated from Tillman et al. 1991
4 from combustion of gas and oil(6.5 MJ/kg from Dogdale 1985) using emission factors of Tillman et al. (1991) and assuming equal amounts of energy being produced with oil and gas
5 Boustead 1993a
6 average values for refined oil products from Boustead (1993b) probably underestimated
7 emission factors from Habersatter & Widmer (1991) assuming the relation between fossil fuels and hydropower/nuclear power to be 6/94 for Sweden and 62/38 for Germany (Tillman et al. 1991), emissions from hydropower and nuclear power to be negligible and all fossil fuel to be coal (50 kWh is produced in Germany; 346 kWh in Sweden)

Uncertainty is estimated to 5% for CO and CO_2. The other emissions depend more on the actual conditions and the uncertainty therefore depends on the quality of the sources: 10% on enterprise estimates (Österdal), 50% on other sources.

3.6 The life cycle of the reusable cotton napkin "BleService"

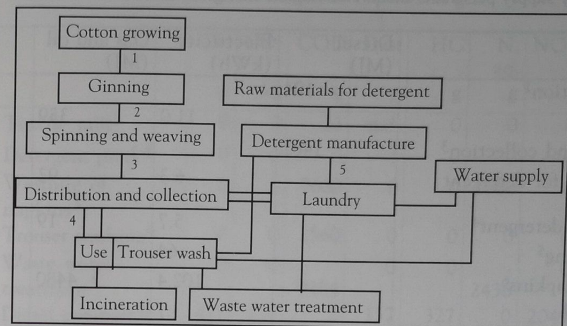

Figure 2. Flow chart for BleService napkins

3.6.1 Material flow

The BleService napkin is produced from cotton and comes in 3 sizes. The average weight taking into account the relative share of different sizes is 108 g.

The material flow related to 6400 changes of BleService napkins is calculated as follows (Numbers in italics refer to figure 2):

Napkins used *(4)* (108 g/napkin * 6400 changes) 691 kg
New napkins *(3)* (691 kg : 150 changes/napkin) 4.6 kg
which requires:
Cotton *(1+2)* (4.6 kg + 1.2 kg waste in carding) 5.8 kg
Washing of 691 kg napkins (containing 269 kg urine and stool) requires:
Detergent *(5)* (1.8 g/napkin change + 150 g * 51.2 trouser washes) 19.2 kg
Water (2 l/napkin change + 90 l/trouser wash x 51.2 washes) 17.4 m^3

3.6.2 Energy supply

Table 4. Energy supply per 6400 BleService napkin changes

	Diesel (MJ)	Electricity (kWh)	Gas and oil (MJ)
Cotton production[1]	104		
Textile mill[2]		11.0	359
Distribution and collection[3]	1467		
Raw materials for detergent production[4]		6.3	92
Production of detergent[4]		5.7	19
Trouser washing[5]		64	
Washing of napkins[6]		102.4	4480
Water supply[7]		3.7	
Waste water treatment[8]		31.3	26
Total	1571	224.4	4976

1 Different sources report from 13000-23000 MJ per t lint out of which 2-15% is from cotton growing. We use 18000 MJ +/- 5000 MJ
2 enterprise specific data (Michaelsen 1993)
3 enterprise specific average calculated from records of BabyBackup
4 enterprise specific data (Danachem A/S 1991)
5 enterprise specific average estimates (own investigation: trousers are washed once a week in the day nurseries own washing machines at 60 ºC; with 125 napkin changes per week, 51.2 washes are equivalent to 6400 napkin changes); uncertainty 40%
6 enterprise specific data (Hansen 1993b)
7 geographically specific data (Hansen 1993a); uncertainty 22%
8 enterprise specific data (Prisum 1993): The typical load of municipal waste water in Storeby is 500 g COD, 43 g N and 10 g P per m^3. The load of the waste water from the BleService system is approximately 600 g COD, 150 g N and 85 g P per m^3. 75% of the electricity consumption and all the thermal energy is related to the concentration of the waste water which may best be expressed by the N content (Nielsen 1993). The treatment of the waste water from the BleService system is therefore responsible for an energy consumption in waste water treatment of 1.8 kWh electricity (25% x 0.625 kWh + 75% x 0.625 kWh x 150 g/43 g) and 1.5 MJ oil (440 MJ x 150 g/43 g) per m^3 waste water.
Uncertainty is 10% unless otherwise stated.

3.6.3 Emissions

Table 5. Emissions per 6400 BleService napkin changes

	CO	CO_2	COD	Dust	HC	N, aq.	NO_x	P, aq.	SO_2
	g	kg	g	g	g	g	g	g	g
Textile mill[1]	0	0	23	n.d.	0	0	0	4	0
Detergent prod.[4]	0	0	3	1	0	0	0	<0.1	0
Washing of napkins[3]	0	0	7680	0	0	2560	0	1088	0
Trouser washing[4]	0	0	2560	0	0	0	0	410	0
Waste water treatment[5]	0	0	-9484	0	0	-2436	0	-1479	0
Diesel combust.[6]	471	124	2	157	327	0	2049	0	242
Electricity prod.[7]	244	224	0	105	3	0	69	0	1319
Gas combustion[8]	5	275	0	~ 0	0.2	0	746	0	10
Total	720	623	782	>263	330	124	2864	23	1571

n.d. = no data available
1 calculated on basis of enterprise specific input data (Michaelsen 1993)
2 enterprise specific data (Danachem A/S 1991 and product data sheets)
3 enterprise specific COD- and P-values from Hansen (1993), N estimated as 15% and 5% of dry matter of urine and stool, respectively, based on 28 ml of urine with 5% dry matter and 14 g stool with 30% dry matter calculated from Vert (1980) assuming an average of 7 napkin changes per day equivalent of 6400 changes in 2.5 years. Also the COD and P values from Hansen (1993) have been checked against theoretical calculated values from detergent, urine and stool
4 enterprise specific average estimates (own investigation: trousers are washed once a week in the day nurseries own washing machines using 150 g detergent; with 125 napkin changes per week, 51.2 washes are equivalent to 6400 napkin changes)
5 calculated in relation to legal limits for waste water output (15 g BOD ~ 45 g COD, 8 g N and 1.5 g P per m^3)
6 Tillman et al. 1991
7 emission factors from Habersatter & Widmer (1991) for electricity from coal (Disregarding the 6 kWh for detergent raw materials, all electricity in the BleService life cycle is consumed in Denmark. According to Garde (1993) nearly all Danish electricity is produced from coal).
8 emission factors from Tillman et al. (1991) natural gas fired burners have been used for all thermal energy, since the main contributors (textile mill and laundry) are using natural gas (Michaelsen 1993 and Hansen 1993b).
Uncertainty is estimated to 25% for emissions to water, 5% for CO and CO_2, and 50% on other emissions.

3.7 Total environmental effects of the two napkin systems

3.7.1 Consumption of fossil fuels

Table 6. Fossil fuel consumption for the two napkin systems

	5300 Carefree paper napkins	6400 BleService napkin changes
Diesel	416 MJ	1571 MJ
Electricity	(from coal)[1] 567 MJ	(from coal)[2] 2444 MJ
Thermal energy for processing	(from oil/gas) 5576 MJ	(mainly from gas) 4976 MJ
Total fossil fuels used	6428 MJ	8991 MJ
Recovered energy	-5300 MJ	
Fossil fuels -recovered energy	1128 MJ	8991 MJ

1 assuming efficiency factor 0.33 (Habersatter & Widmer 1991),50 kWh to be produced in Germany; 346 kWh in Sweden and the amount of fossil fuels to be 6% for Sweden and 62/38 for Germany (Tillman et al. 1991)
2 assuming efficiency factor 0.33 (Habersatter & Widmer 1991) and all electricity to be produced in Denmark (100% fossil fuels)

3.7.2 Water consumption

Pulp production is responsible for approximately 90 % of the water consumption of the paper napkin life-cycle. 40 m^3 water is used to produced 1 ton of pulp. Therefore 9.7 m^3 water is needed for producing 244 kg pulp used to make 5300 Carefree paper napkins. Practically all of the water used is surface-water.

In the life cycle of the cotton napkin, nearly all the water consumed is drinking water used in the washing processes (total 17.4 m^3).

3.7.3 Air emissions

Air emissions are mainly related to the energy consumption. Therefore, it is no surprise that the figures in table 7 reflect the distribution of the total energy consumption from table 6. However, the emissions from the different types of energy and burners are quite different (diesel engines have relatively high emissions especially for NO_x, energy from wood does not contribute to CO_2-emissions but has relatively high emissions of CO, incineration has relatively high dust emissions, coal combustion gives high SO_2-emissions, etc.). This explains the variations between the different emissions.

The recovered energy from incineration of the Carefree napkin substitutes coal combustion in the co-generation plant which is used to supplement the district heating. The emission factors of Habersatter & Widmer (1991) for industrial coal fired co-generation plants has been used. The effect of this is shown in the second column of table 7. The main effect is that figures for CO_2 and SO_2 are substantially reduced (actually they come out negative when avoided emissions are taken into account).

*Table 7. Main air emissions (in kg) for the two napkin systems. *The BleService figure for dust is underestimated since data on dust from gin and textile mill is missing.*

emissions in kg	Carefree incinerated without heat recovery	Carefree incinerated with heat recovery	BleService
CO	12.2	11.7	0.7
CO_2	397	-25	623
Dust	5.3	4.8	0.3*
HC	2.3	2.2	0.3
NO_x	3.0	1.8	2.8
SO_2	1.1	-1.8	1.6

3.7.4 Water emissions

Values for COD, N and P (after waste water treatment) are summarised in table 8. The water emissions for Carefree paper napkin occur primarily in the pulping process while emissions from the reusable cotton napkin primarily come from the washing process.

Table 8. Main water emissions from the two napkin systems.

Emissions in g	Carefree	BleService
COD	8800	784
N	36	124
P	4	23

3.7.5 Welfare effects

Both the pulp production and the textile production (ginning, spinning, weaving) and the transport processes are noisy. It has not been possible to obtain figures for the specific noise levels. However, it should be noted that the BleService system involves more road traffic than the paper napkin and that the majority of this takes place in city areas (distribution and collection of the napkins) involving not only noise but also other nuisances (fear of accidents, smell etc.) which are not accounted for in the above values for resource consumption and emissions.

3.7.6 Economics

The price of Carefree is 1.64 DKK per napkin or *8692 DKK for 5300 napkins*. The price of BleService is 30 DKK for the delivery + 1,08 DKK per napkin. Assuming delivery twice a week, an average of 25 children in each day

nursery and 5 days a week, the total price will be 195 DKK per week, 1.56 DKK per napkin change or *9984 DKK for 6400 napkin changes*. For private families delivery is only once a week, giving a total cost of 66.75 DKK (for an average of 34 napkins) or 1.96 DKK per napkin change.

3.8 Evaluation

The Carefree paper napkin system have environmental advantages on the following parameters: consumption of fossil fuel and drinking water resources, emissions of CO_2 and SO_2.

The BleService reusable cotton napkin system have environmental advantages on the following parameters: emission of CO, HC and COD.

For a final evaluation we believe that the consumption of fossil fuel and emission of CO_2 will have most weight, due to their long-term and possibly irreversible effects. This points to the paper napkin as the preferable environmental option. We believe that this conclusion can only be reversed if the other emissions were an order of magnitude larger (e.g. if the COD-emission of the paper napkin system was 100 kg rather than 10 kg).

Also, from an economic point of view, the paper napkin system is preferable.

3.9 Sensitivity analysis

The following uncertainties should be mentioned:

- Defining functional unit of product: 5%
  (10% on the ratio between the two systems)
- Lifetime of BleService napkin: 50%
  (on cotton and napkin production)

- Lifetime of BleService trousers: <2%
  (total weight of trousers is 1% of cotton weight)
- Limitations in life cycle: <1%
- Weight of napkin: 10%
- Energy supply data: 10-50%
- Emission data: 10-50%

A rough estimate of the maximum uncertainty is therefore 400%. The difference between the two systems is approximately 800% on fossil fuel, which means that this part of the conclusion is certain. Our sensitivity analysis has therefore concentrated on the difference in CO_2 emissions which is only 50% (not accounting for heat recovery).

The sensitivity analysis has been performed by changing all values so that the CO2 emission data shows the maximum possible bias towards the BleService system within the range of the estimated unsertainty limit. The result is given in table 9. As can be seen, this maximum bias in favour of the BleService system does change this part of the conclusion, but the difference is not very large. The probability of all uncertainties being in favour of one of the systems is very small. Thus, an overall estimate of the certainty of the conclusion is 95%.

Table 9. CO_2-emissions from the two napkin systems. The second line gives the result of a sensitivity analysis giving maximum bias to the benefit of the BleService system.

CO_2-emissions in kg	Carefree incinerated without heat recovery	Carefree incinerated with heat recovery	BleService
Actual result	397	-25	623
Biased result (sensitivity analysis)	510	162	436

3.10 Conclusion

The Carefree paper napkin system has a lower consumption of fossil fuel and drinking water resources, and lower emissions of CO_2 and SO_2 compared to the BleService reusable cotton napkin system. The BleService system does not have comparable advantages. The Carefree napkin is therefore recommended. Lowering the COD-emission from the pulp production would give further advantages to the paper napkin. The uncertainty on this conclusion is very low (<5%).

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* Please note the disclaimer in front of this publication

4 Example report 2

Disposable versus reusable baby napkins – A life cycle study

by Frank Friday

R. Crusoe Associates Ltd.

La Valleta, Malta

June 1993

4.1 Summary

The reusable cotton napkin system BleService is compared to the disposable paper napkin Carefree with respect to the environmental impacts of the two systems taking into account all effects in the life cycle of the products. The purpose of the study is to determine which of the two systems is preferable for use in the County-operated day nurseries in Storeby, Denmark. The reusable cotton napkin is favourable on most significant environmental parameters and does not involve extra costs. It is therefore recommended that Storeby County introduces the BleService system in all their day nurseries.

4.2 Objectives and target group

This study compares the environmental effects of the disposable paper napkin Carefree from Barth AG, Kiel and the reusable cotton napkin service system BleService operated by the company BabyBackup, Storeby.

The study was carried out in May 1993 by Frank Friday of R. Crusoe Ltd., La Valleta for Storeby County, Denmark. The objective of the study is to determine which of the two available baby napkin systems is preferable for use in the County-operated day nurseries with respect to the total environmental impact of each system, taking into account all effects in the life cycle of the products.

4.3 Financial involvement

The study is financed by Storeby Council.

4.4 Product definition and included product alternatives

The products to be compared are the disposable paper napkin Carefree and the reusable cotton napkin service system BleService, operated by the company BabyBackup. BleService is a rental system in which the users (child care centres or individual families) rents a specially designed cotton napkin which is delivered and collected twice weekly by BabyBackup, Storeby (once weekly for individual families).

The product unit to be compared is:

"yearly napkin changes in a day nursery in Storeby County."

The number of napkins used will be the same for the two systems, since the children are changed twice while staying at the day nursery: once at about 11 o'clock and once more shortly before they are collected by their parents. In both systems, the second change will be with a disposable napkin to keep the reusable napkins from disappearing (Garde 1993). Thus, the comparison is between one daily change with a reusable napkin and one daily change with a disposable napkin. The average number of children in the day nurseries in Storeby County is 25. Thus, the yearly consumption of napkins in one day nursery is 25 napkins/day x 5 days/week x 52 weeks = 6500 napkins. This figure is used in the further calculations.

The lifetime of the reusable cotton napkin is estimated by BabyBackup to be 150 changes. To improve the lifetime of their napkins, BabyBackup removes spots form the napkins with sodium hypochlorite (4% chlorine). The estimate seems reasonable since both Franklin Associates Ltd. (1990) and Lehrburger et al. (1991) estimate a lifetime of 180 washes for napkins washed in private homes and a lifetime for napkins in a service system of 50 and 78 washes respectively (presumably without spot removal).

4.5 The life cycle of the paper napkin "Carefree"

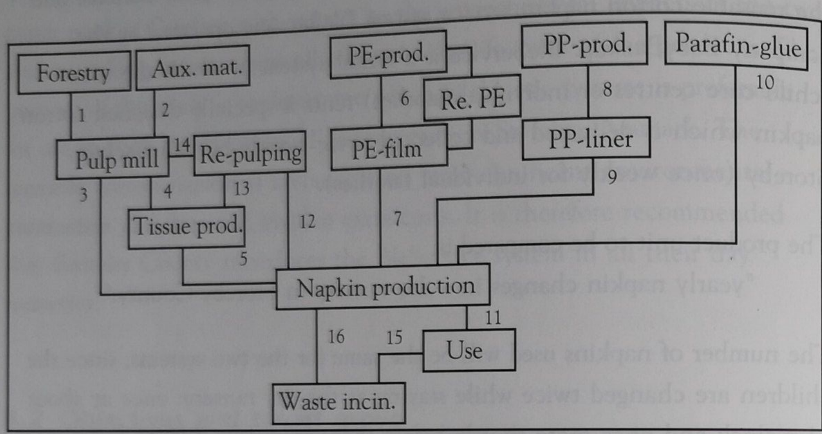

Figure 1. Flow chart for Carefree paper napkin.

4.5.1 Material flow

The paper napkin Carefree is found in several sizes to suit children of different age and sex. This investigation is based on Carefree Maxi which is used for the majority of children at the day nurseries. The composition of Carefree maxi is:

Fluff pulp:	49 g
Paper tissue:	5 g
PP-lining:	5 g
PE-foil:	5 g
Paraffin-glue:	6 g
Total weight:	70 g

Barth AG estimates an average waste of 10% in the production, of which the paper waste is reused by the paper mills and the rest goes to industrial

incineration. Carefree maxi is delivered in packs of 64 napkins in an 80 g PE-foil.

If the waste and the packaging are included, the total material requirements per napkin are:

Fluff pulp:	53.9 g
Paper tissue:	5.5 g
PP-liner:	5.5 g
PE-foil:	6.8 g
Paraffin-glue:	6.6 g

The material flow related to 6500 changes of Carefree can therefore be calculated as follows (numbers in italics refer to figure 1):

Pulp:	
Fluff pulp for napkins *(3)*	(53.9 g x 6500) 350 kg
Pulp for tissue paper *(4)*	(5.5 g x 6500 + 5% loss) 38 kg
Waste pulp and paper *(12)*	(10% of 350 kg) -35 kg
Net amount of pulp for which is needed:	353 kg
Wood *(1)*1.8 cubic metres (5.1.m^3 / t pulp) or (wet weight , 50% water)	1835 kg
Auxiliary materials for pulp *(2)*	(155 kg / t pulp) 54.7 kg
Oil derivatives:	
PE *(6)*	(6.8 g x 6500) 44 kg
PP *(8)*	(5.5 g x 6500) 36 kg
Paraffin glue *(10)*	(6.6 g x 6500) 43 kg
Use:	
Napkins incl. packaging *(11)*	(71 g x 6500) 462 kg

Waste treatment:
Used napkins *(15)* 462 kg
Industrial waste *(16)* 12 kg
(10% waste in napkin production minus paper and packaging)

4.6 The life cycle of the reusable cotton napkin "BleService"

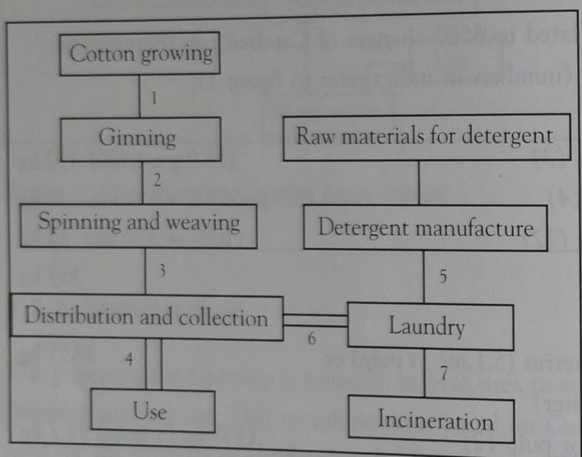

Figure 2. Flow chart for BleService napkins

4.6.1 Material flow

The BleService napkin is produced from cotton and comes in 3 sizes. The weight of the largest size (comparable to Carefree Maxi) is 115 g.

The material flow related to 6500 changes of BleService napkins is calculated as follows (numbers in italics refer to figure 2):

Napkins used *(4)* (115 g/napkin x 6500 changes) 748 kg
New napkins *(3)* (748 kg : 150 changes/napkin) 5.0 kg
which requires:
Lint *(2)* (5.0 kg + 20% loss in textile mill) 6.3 kg
Cotton bolls *(1)* (the 6.3 kg lint is only 35% of the harvested weight) 18 kg
Washing of 6500 dirty napkins requires:
Detergent *(5)* (1.8 g per dirty napkin + 150 g x 52 trouser washes) 19.5 kg
Water (2 l per dirty napkin + 90 litres x 52 washes) 17.7 m^3

4.7 Environmental effects of the paper napkin "Carefree"

4.7.1 Transports

The transports related to 6500 changes of Carefree are:

1. Forest to pulp mill: 1835 kg transported 60 km by rail and 90 km by road (Tillman et al. 1991).
2. From chemical producers to pulp mill: 55 kg transported 100 km by road (estimated).
3, 12. From pulp mill in Säffle to napkin producer in Kiel including return waste: 350 kg transported 700 km by rail (actual distance). A factor 2 has been used to accommodate for the high volume (Jensen 1993).
4, 13. Pulp mill to tissue producer including return waste: 38 kg transported 200 km by road.
5. From tissue producer to napkin producer: 36 kg transported 700 km by rail (estimates).

6. From PE-producer (assumed to be in Steningsund) to PE-film producer including return waste: 48 kg transported 250 km by road.
7. From PE-film producer in Hässleholm to napkin producer: 44 kg transported 500 km by rail.
8. PP-producer (assumed to be in Steningsund) to PP-liner producer: 36 kg x 150 km by road.
9. PP-liner producer in Halmstad to napkin producer: 36 kg transported 550 km by rail.
10. Paraffin-glue producer to napkin producer: 43 kg transported 1000 km by road (estimated).
11. From napkin producer to napkin user in Storeby County: 462 kg transported 300 km by rail. A factor 2 has been used to accommodate for the high volume (Jensen 1993).

15, 16 Waste transport: 474 kg transported 30 km in waste truck (estimated). A factor 1.5 has been used to accommodate for extra fuel use in waste trucks (Stilling 1993).

The total figures can be seen in table 1.

Table 1. Transport for 6500 Carefree napkins.

	kg	Road km	Rail km	Total road tkm	Total rail tkm
1. Forest to pulp mill	1835	90	60	165	110
2. Chemicals to pulp mill	55	1000		55	
3 & 12. Säffle to Kiel:	350		700		245
4 & 13. Säffle to tissue prod	38	200		8	
5. Tissue prod to Kiel:	36		700		50 (factor 2)
6. PE to Hässleholm	46	250		12	
7. Hässleholm to Kiel	44		500		22
8. Steningsund to Halmstad	36	150		5	
9. Halmstad to Kiel	36		550		20
10. Paraffin to Kiel	43	1000			43
11. Kiel to napkin user	462		300		277 (factor 2)
15-16. Waste transport	474	30 (waste)		21 (factor 1.5)	
Sum				266	767

To calculate the equivalent energy consumption we use figures for Danish conditions according to Miljøministeriet (1992): 3.1 MJ per tkm for trucks and 1.0 MJ per tkm for rail transport giving a total of 1592 MJ.

4.7.2 Forestry

According to Tillman et al. (1991) the felling of trees use 88 MJ diesel/m^3 and the inherent energy (feedstock energy) in wood is 9500 MJ per m^3.

4.7.3 Production of auxiliary chemicals for pulp production

1.7 kWh electrical energy per kg (Estimate by Österdal 1993).

4.7.4 Pulp production

The fluff pulp is produced by Big Fluff AB, Säffle, Sweden (Information supplied by Österdal, unless otherwise stated):

Input:		5.1 cubic metre wood under bark
		155 kg auxiliary chemicals
		40 m^3 water
		200 kWh electricity
Output:		1000 kg pulp
Emissions:		
	To air:	31.75 kg CO (calculated from Tillman et al. 1991)
		800 g dust (Tillman et al. 1991)
		3.175 kg HC (calculated from Tillman et al. 1991)
		20 g H_2S
		2 kg NO_x
		7 g odorous compounds (Tillman et al. 1991)
		90 g SO_2 (Tillman et al. 1991)
		1.2 kg S_{tot}
	To water:	44 kg COD (34 kg after waste water treatment)
		200 g N (140 g after treatment)
		50 g P (12 g after treatment)
	Solid waste:	50 g (Tillman et al. 1991)

Debarking is a very noisy process. Measurements average 135 dB(A) (Miljö-net 1990).

4.7.5 Tissue production

The tissue is produced by different Swedish industries. The data on this process is taken from Dogdale (1985):

Input:	1040 kg pulp
	1060 kWh electricity
	6500 MJ energy from gas or oil
Output:	1000 kg tissue
	50 kg industrial paper waste

The water circuits of the production systems are generally closed. A glue is added to the pulp, but the amount (10 kg per t of tissue is estimated by Österdal) is negligible compared to the glue used in napkin production. Emissions from the combustion of gas and oil are calculated with the figures from Tillman et al. (1991) assuming equal amounts of energy being produced with oil and gas:

42 g CO
439 kg CO_2
98 g dust
59 g HC
975 g NO_x
1287 g SO_2

4.7.6 PE-production

Figures for LDPE production have been taken from Boustead (1993a):

Input:	79 MJ oil and gas including 48 MJ inherent energy
	10 MJ electrical energy
	24 l water
Output:	1 kg LDPE-granulate
Emissions:	0.9 g CO
	1.25 kg CO_2
	1.5 g COD
	3 g dust
	21 g HC

	12 g NO_x
	9 g SOx

4.7.7 PE-Film production

The PE-film is produced by Flatplast AB, Hässleholm, Sweden. Information supplied by A. Svensson, Flatplast AB:

Input:	1050 kg LDPE-granulate
	500 kWh electricity
	(Tillman et al. 1991 report a figure of 860 kWh)
Output:	1000 kg PE-foil
	50 kg industrial PE-waste

Additives may be added to the granulate, but we have not been able to obtain any information on this.

4.7.8 PE-recycling

Tillman et al. (1991) give a figure of 3 MJ electricity per kg recycled PE.

4.7.9 PP-production

Figures for LDPE production have been taken from Boustead (1993a):

Input:	73 MJ oil and gas including 48 MJ inherent energy
	7 MJ electrical energy
	3 l water
Output:	1 kg PP-granulate
Emissions:	0.7 g CO
	1.1 kg CO_2
	0.4 g COD

	2 g dust
	13 g HC
	10 g NO_x
	11 g SOx

4.6.10 PP-liner-production

The PP-liner is produced by Polynet AB, Halmstad, Sweden. Information supplied by G. Bergled, Polynet AB:

Input:	1000 kg PP-granulate
	3000 kWh electricity
	(Kindler & Nikles 1980 give a figure of 833-1666 MJ/kg)
Output:	1000 kg PP-liner

The processing waste is recycled back into the production. Additives may be added to the granulate, but we have not been able to obtain any information on this.

4.7.11 Paraffin-glue production

We have not been able to obtain any data on this production. We have therefore used average values for refined oil products from Boustead (1993b):

Input:	50 MJ oil including 45 MJ inherent energy
	0.2 kg water
Output:	1 kg refined oil product
Emissions:	0.08 g CO
	284 g CO_2
	0.01 g COD
	0.34 g dust
	2.9 g HC

2.9 g NO_x

1.8 g SOx

4.7.12 Napkin production

Barth AG in Kiel, Germany manufactures the Carefree napkin from its basic components:

Input:	46 g fluff pulp
	5 g paper tissue
	4.4 g PP-liner
	5.5 g PE-foil
	5.5 g paraffin-glue
	0.008 kWh electrical energy (Barth AG: calculated from 1992 figures of total energy consumption and weight of total production)
Output:	1 napkin packaged in PE-foil
	4 g industrial paper waste
	1.4 g industrial solid waste (inherent energy 43 MJ/kg)

4.7.13 Re-pulping of paper waste

Tillman et al. (1991) give the following figures:

Input:	1000 kg waste paper
	972 MJ electricity
Output:	1000 kg pulp
Emissions:	18 kg COD

We have not been able to obtain a figure for water consumption for re-pulping, but a maximum estimate must be half of the water consumption for native pulp, i.e. 20 m^3.

4.7.14 The use phase

The use phase takes place in Storeby County, Denmark:

Input:	1 napkin packaged in PE-foil
Output:	1 dirty napkin
	1 g PE-foil from package

The extra volume of solid waste may demand extra space and containers, but it is assumed to be equal to the need for space and containers for storing the re-usable napkins until they are collected.

4.7.15 Incineration of used napkins and packaging

The used napkins and the used packaging material are assumed to be incinerated. The emissions are calculated using the emission factors of Tillman et al. (1991).

Input:	1 dirty napkin
	1 g PE-foil from package
Output:	0.8 g CO (1 g/MJ x 0.8 MJ paper)
	44g CO_2 (3138 g/kg x 14 g petrochemicals calculated. as PE)
	0.92 g dust (20.0 g/kg x 46 g paper)
	0.08 g HC (0.1 g/MJ x 0.8 MJ paper)
	0.22 g NO_x (2.67 g/kg x 46 g paper + 6.88 g/kg x 14 g PE)
	0.024 g SO_2 (0.03 g/MJ x 0.8 MJ paper)
	1 g solid waste (Ash: 20 g/kg x 46 g paper)

4.7.16 Energy supply

Diesel is used in transport and in forestry. The felling of wood uses 88 MJ/m^3 x 1.8 m^3 = 158 MJ which shall be added to the 1592 MJ diesel used in transportation giving a total of 1750 MJ diesel for which the following emissions figures per MJ have been used (Tillman et al. 1991) :

0.3 g CO
78.6 g CO_2
0.1 g dust
0.208 g HC
1.304 g NO_x
0.154 g SO_2

The use of electricity can be summarised as follows:

Aux. chem. for pulp:	93.0 kWh
Pulp mill:	70.0 kWh
Tissue production:	40.3 kWh
PE-production:	123.2 kWh
PE-film production:	22.0 kWh
PE-recycling:	1.6 kWh
PP-production:	68.4 kWh
PP-liner:	108.0 kWh
Napkin production:	52.0 kWh
Repulping:	9.5 kWh
Total	588.0 kWh

Disregarding the 52 kWh used in Kiel, all energy consumption takes place in Sweden. Since the marginal Swedish electricity is produced at Danish coal-fired power plants, the efficiency and emission factors for these have been used, taken from Emborg et al. (1991) supplemented with the figures for CO and dust emissions from Habersatter & Widmer (1990). We have assumed that 90% of the SO_2-emissions and 80% of the NO_x-emissions have been removed by wet-scrubbing and selective catalytic reduction. The figures for pre-combustion emissions have been calculated assuming that all coal is hard coal and transported on average 12000 km by ship using figures from Habersatter & Widmer (1991). The sum figures for 1 kWh are:

CO:	1 g
CO_2:	1 kg
HC:	0.16 g
NO_x:	0.51 g
SO_2:	1.8 g
Solid waste:	67 g
Primary energy consumption (coal):	8.2 MJ

These figures have been used for all electricity, since they are approximately correct also for the marginal German electricity.

The use of fossil fuels used for thermal energy in processing can be summarised as follows:

Tissue production:	(5.5 g/napkin x 6500 napkins x 6.5 MJ/kg) 232 MJ
PE production:	(31 MJ/kg x 44 kg) 1364 MJ
PP production:	(25 MJ/kg x 36 kg) 900 MJ
Glue production:	(5 MJ/kg x 43 kg) 215 MJ
Total:	2711 MJ

The emissions from the combustion of oil and gas in the above processes have been included in the reports of each process.

The amount of inherent energy in raw materials can be summarised as follows:

Wood:	(9500 MJ/m^3. x 1.8 m^3) 17100 MJ
PE:	(48 MJ/kg x 44 kg) 2112 MJ
PP:	(48 MJ/kg x 36 kg) 1728 MJ
Glue:	(45 MJ/kg x 43 kg) 1935 MJ
Total:	22875 MJ

4.8 Environmental effects of the reusable cotton napkin "BleService"

4.8.1 Transports

The transports related to 6500 changes of BleService are:

1. Cotton bolls from field to gin: 6.5 kg transported 50 km (negligible).
2. Cotton from gin in Turkey to textile mill in Denmark: 6.3 kg transported 3000 km by rail.
3. Napkin from textile mill to napkin distributor: 5.0 kg transported 200 km (negligible).
4. Napkin distribution and collection: From the records of BabyBackup an average distance of 200 km to visit 50 customers can be calculated. Thus, the average is 4 km per customer. Delivery is twice a week for day nurseries, giving 104 deliveries annually x 4 km = 416 km. The delivery van runs 10 km per l diesel with a heat value of 35.6 MJ.
5. Detergent from raw materials to laundry: 20 kg transported 1300 km by road (estimated).
6. Napkins from distributor to laundry: 748 kg transported 60 km by road. A factor of 1.5 is used to compensate for the low density of napkins (Jensen, 1993).
7. Withdrawn napkins to incineration: 5.0 kg transported 30 km (negligible).

The important contributions are summarised in table 2.

Table 2. Transport for 6500 changes of BleService napkins

	kg	km	MJ/tkm	MJ total
2. Cotton Turkey - Denmark	6.3	3000	1 (rail)	19
4. Distribution/collection		416		1481
5. Detergent	20	1300	3.1 (truck)	81
6. Distributor to laundry	748	60	4.65 (truck; low density load)	209
Total				1790

4.8.2 Cotton growing

The cotton is Ecotton® organic cotton grown in Kharamanmaras, Turkey. Information is supplied by van Esch (1993). Organic cotton growing implies that no pesticides are used and that fertilisation is restricted to leguminous wastes and animal manure (regarded as a waste from meat production). Thus, this particular cotton growing is regarded as having no emissions. Energy consumption for irrigation and working the land is estimated to 7500 MJ per ha. The yield is 5700 kg per ha giving an energy consumption of 1300 MJ diesel per t cotton bolls.

4.8.3 Cotton ginning

In the gin (situated at a farm in Turkey) the seeds are removed and the cotton is cleaned and dried. Information from van Esch (1993):

Raw materials: 100 kg cotton
20 l water
1650 MJ diesel

Products: 35 kg lint (cotton fibre)
62 kg cotton seeds
(for oil, industrial products and fodder)
3 kg waste

Since the price of lint per kg is approximately the same as the price of cotton seeds per kg, the allocation is done on a mass basis.

4.8.4 Textile mill

The lint is spun and woven at Angel A/S, Silkeborg, Denmark. Information supplied by Michaelsen, Angel A/S:

Input: 100 kg lint
1000 l water
1.25 kg detergent
195 kWh electricity
6240 MJ thermal energy

Output: 80 kg cotton napkins
20 kg cotton waste
(mainly loss in carding; sold to the pulp industry)
400 g COD
69 g P

Emissions are calculated from the input of detergent. For sizing and desizing 1 kg starch and 1.5 kg plant oil are used per 100 kg lint. These substances are regarded as negligible in comparison to the amounts of glue used for disposable napkins. Bleaching follows the same procedures as for paper pulp. Since the amount of cotton is less than 3% of the amount of pulp for disposable napkins this process is omitted. No environmental effects are allocated to the by-product "cotton waste" since the amount (1.25 kg for 5

kg napkins) is negligible compared to the amount of pulp used for the disposable napkin.

4.8.5 Use

The use phase takes place in Storeby County, Denmark:

Input: 1 napkin packaged in PE-foil

Output: 1 dirty napkin
1 g PE-foil from package

The reusable cotton napkin is used together with a pair of plastic lined cotton trousers also delivered by BabyBackup. The trousers are washed once for every 5 napkin changes (once a week). One pair of trousers used in a day nursery is estimated to last 10 years (2600 napkin changes). The equivalent of 6500 napkin changes is thus 2.5 pairs of trousers. According to the information sheet from the supplier, the composition of the complementary cotton trousers is 27 g cotton, 9 g PE filling, 4 g polyester lining, 8 g Velcro-zipper (polyester). Thus, the material requirement and weight of the 2.5 pairs of trousers (120 g) is negligible compared to that of the cotton napkins (5 kg), and their production and washing have therefore not been included in the analysis.

4.8.6 Raw materials for detergent production

In Danachem A/S environmental report 1991 the energy consumption for production of inorganic chemicals is reported to be 3100 MJ thermal energy and 285 kWh electricity per t detergent (allegedly calculated from suppliers data) while the energy consumption for production of linear alkyl benzene sulphonate (LAS) is reported as 14000 MJ thermal energy and 370 kWh electricity per t. Since 12% of the napkin detergent Danasoft is LAS, the total figures for the raw materials of 1 t detergent will be:

Thermal energy: 0.12 x 14000 MJ + 3100 MJ = 4800 MJ

Electrical energy: 0.12 x 370 kWh + 285 kWh = 330 kWh

Inherent energy in LAS is estimated by Nylander (1991) to be 32 GJ/t (data extrapolated from values for similar substances).

4.8.7 Production of detergent

The detergent used by Storeby Linen Service A/S is Danasoft produced by Danachem A/S. The information below is calculated from Danachem A/S environmental report from 1991 combined with data sheets of Danasoft:

Inputs:	121 kg linear alkyl benzene sulphonates
	252 kg sodium tripolyphosphate
	200 kg sodium sulphate
	150 kg sodium perborate
	90 kg sodium carbonate
	70 kg sodium silicate
	minor quantities of CMC, colorants and perfume
	113 l water
	133 kg cardboard packaging material
	300 kWh
	1000 MJ thermal energy
Output:	1000 kg detergent in 3 kg packages.
Emissions:	63 g BOD
	130 g COD
	30 g dust
	0.1 g P

The cardboard packaging material (2.6 kg for 19.5 kg detergent) is regarded as negligible compared to the amounts of pulp and paper used for the disposable napkin.

4.8.8 Washing of napkins

The napkins are washed at Storeby Linen Service using 2 prewash rinses, 2 washings and 5 rinses.

4% of the napkins are washed twice, the second time without prewash rinses and with sodium hypochlorite (4% chlorine) in the first of the two washings. Information supplied by Hansen, Storeby Linen Service:

Inputs:	10 dirty napkins
	20 litres of ion-exchanged drinking water
	18 g Danasoft detergent
	0.05 ml sodium hypochlorite (4% chlorine)
	0.19 cubic metres gas x 36.6 MJ/m^3 = 7 MJ
	0.16 kWh electricity
Output:	10 clean napkins
Emissions:	12 g COD
	1.7 g P

The amount of sodium hypochlorite is regarded as negligible.

4.8.9 Energy supply

The total diesel consumption can be summarised as follows:

Cotton growing:	(1300 MJ/t x 6.5 kg) 8 MJ
Cotton ginning:	(1650 MJ/97 kg x 6.3 kg) 107 MJ
Transport:	1790 MJ
Total:	1905 MJ

for which the emission factors of Tillman et al. (1991) have been used.

The total electricity consumption can be summarised as follows:

Textile mill:	(195 kWh/80 kg x 5 kg) 12.2 kWh
Detergent chemicals:	(285 kWh/t x 19.5 kg) 5.6 kWh
LAS production:	(370 kWh/t x 12% x 19.5 kg) 0.9 kWh
Detergent prod.:	(300 kWh/t x 19.5 kg) 5.9 kWh
Laundry:	(0.16 kWh/10 napkins x 6500 napkins) 104.0 kWh
Total electricity for 6500 napkin changes:	128.6 kWh

Most electricity consuming processes are situated in Denmark. Therefore, the same (Danish) electricity system has been used as for the paper napkins.

The consumption of thermal energy can be summarised as follows:

Textile mill:	(6240 MJ/80 kg x 5 kg) 390 MJ
Detergent chemicals:	(3100 MJ/t x 19.5 kg) 60 MJ
LAS production:	(14000 MJ/t x 12% x 19.5 kg) 33 MJ
Detergent production:	(1000 MJ/t x 19.5 kg) 20 MJ
Laundry:	(7 MJ/10 napkins x 6500 napkins) 4550 MJ
Total thermal energy:	5053 MJ

The textile mill and the laundry are using natural gas. For all thermal energy the following emission figures per MJ have been used (Tillman et al. 1991 for natural gas fired burners):

SO_2: 0.002 g
NO_x: 0.15 g
CO: 0. 001 g
HC: 0.000015 g
CO_2: 55.2 g

The amount of inherent energy in raw materials is:

Cotton:	(17 MJ/kg) 85 MJ
Detergent:	(4 MJ/kg) 78 MJ
Total:	163 MJ

4.9 Total environmental effects of the two napkin systems

4.9.1 Energy consumption

Energy is consumed as diesel, electricity and thermal energy in processes, or as inherent energy (feedstock energy) in materials. Table 3 summarises the energy consumption of the two napkin systems:

Table 3. Energy consumption for the two napkin systems

	6500 Carefree paper napkins	6500 BleService napkin changes
Diesel	1750 MJ	1905 MJ
Electricity	(from coal) 4822 MJ	1055 MJ (from coal)
Thermal energy for processing	(from oil/gas) 2711 MJ	5053 MJ (mainly from gas)
Inherent energy	22875 MJ (mainly in wood)	163 MJ (cotton + detergent)
Total energy as primary energy	32158 MJ	8176 MJ

4.9.2 Water consumption

For the paper napkin life cycle, the pulp production is responsible for approximately 90% of the water consumption (total 14 m³). Nearly all the water consumed in the life cycle of the cotton napkin, is used in the laundry (total 13 m³). The difference between the two systems is negligible.

4.9.3 Air emissions

Table 4. Main air emissions (in kg) for the two napkin systems.

emissions in kg	Carefree	BleService
CO	17.5	0.7
CO_2	1135	558
Dust	6.9	0.3
HC	3.6	0.4
NO_x	5.8	3.3
SO_2	2.4	0.5

Beside the air emissions listed in table 4, the pulp production causes emissions of a number of sulphur compounds (S_{tot} for the life cycle is 0.3 g; H_2S-emissions totals 5 g), some of which are highly odorous.

4.9.3 Water emissions

Values for COD, N and P (after waste water treatment) are summarised in table 5. The water emissions for Carefree paper napkin occur primarily in the pulping process while emissions from the reusable cotton napkin primarily come from the washing process.

Table 5. Main water emissions from the two napkin systems.
**calculated in relation to legal emission limits for Danish municipal waste water (15 g BOD ~ 45 g COD, 8 g N and 1.5 g P per m³)*

Emissions in g	Carefree		BleService	
	before treatment	after treatment	before treatment	after treatment*
COD	16323	12613	7800	585
N	70	49	0	0
P	17	4	1109	20

4.9.5 Solid waste

The largest contribution to solid waste is from the electricity production and thus difference in solid waste follows the difference in electricity consumption (see above). The amount of solid waste is approximately 9 kg for the BleService system and 45 kg for the Carefree napkin.

4.9.6 Welfare

The debarking of wood is a very noisy process. Furthermore, the amounts of processed material is much higher for the Carefree napkin (1835 kg wood, 353 kg pulp) than for the BleService system (6.3 kg cotton fibres).

4.9.7 Economics

The price of Carefree is 1.64 DKK per napkin or *10660 DKK for 6500 napkins*. The price of BleService is 30 DKK for the delivery + 1,08 DKK per napkin. Assuming delivery twice a week, an average of 25 children in each day nursery and 5 days a week, the total price will be 195 DKK per week, 1.56 DKK per napkin change or *10140 DKK for 6500 napkin changes*. The costs of the plastic lined cotton trousers are 70 DKK (100 DKK for woollen trousers) or approximately 0.01 DKK per napkin change and can therefore be omitted.

4.10 Evaluation

The total energy consumption of the paper napkin system is nearly 4 times that of the reusable cotton napkin system. All air emissions are higher for the paper napkin system, from twice as high for the greenhouse gases CO_2 and NO_x to 25 times as high for CO and dust. Furthermore, the paper industry emits highly odorous compounds and involves more noisy processes than the cotton napkin system. The paper napkin system also has higher emissions of solid waste and COD. Only on emissions of phosphorous does the cotton napkin system have a larger environmental effect than the paper napkin system. This emission is from a municipal waste water treatment plant and is thus within the strict Danish emission limits.

An overall environmental evaluation must therefore find advantage in the BleService reusable cotton napkin system. Also from an economic point of view, the cotton napkin system is preferable, giving an economic benefit of 520 DKK annually per day nursery.

4.11 Conclusion

The reusable cotton napkin system BleService has been compared to the disposable paper napkin Carefree. The reusable cotton napkin is favourable on most significant environmental parameters and does not incur extra

costs. It is therefore recommended that Storeby County introduces the BleService system in all their day nurseries.

4.12 References

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* Please note the disclaimer in front of this publication

II

Example answer

1 Introduction

This chapter describes one possible peer-review of two given example life cycle assessment studies. This peer-review does not try to evaluate the actual results of the studies, but consentrates the differences in the way how the reports are made. If the time allows, the reader is recommended to try to create an optimum report by using the information given in example reports. It is possible to produce an better report by selecting the system boundaries and datasources in an optimum way from the reports.

2 Comparative peer review of two life cycle studies on baby napkins

Two reports have been prepared for Storeby County, Denmark comparing the environmental effects of two existing systems for baby napkins: Disposable paper napkins and a reusable cotton napkin service system. The two studies have been carried out simultaneously in the spring of 1993 by two independent consultants: Elsie A. Masters of Masters & Co. and Frank Friday of R. Crusoe Associates Ltd. The two studies are based on much the same data but reach different conclusions mainly due to differences in the system boundaries. This comparative peer review found positive and negative aspects in both reports.

3 Comments on the two reports

OBJECTIVES AND SCOPE

Masters' report

There is a clear definition of the area for which the conclusion is valid and an explicit warning not to use the study out of its context.

The study does not investigate or suggest improvements to either of the two systems, therefore obvious opportunities for optimisation may be overlooked (e.g. washing the trousers at the laundry rather than in the day nurseries own washing machines).

Friday's report

There are no clear reservations as to the applicability of the conclusion in other contexts.

ALTERNATIVES INCLUDED

The author considers other alternatives than those actually investigated and gives reasons for their exclusion from the study.

The author does not discuss other possible alternatives than the two investigated.

FUNCTIONAL UNIT (EQUIVALENT USAGE)

The author includes a detailed (and superfluous) discussion on equivalent usage of the two types of napkin over the entire napkin period (2.5 years) although the objective of the study only relates to the day nurseries. It would be preferable to base the comparison on the way in which the two types of napkins are actually used in the day nurseries and how this may or may not influence the use-patterns in the households.

It is not clear whether the basic assumption of equal changes in the day nursery is based on a theoretical assumption of the number of napkin changes or whether the timing and thus the frequency of the changes has actually been investigated.

FUNCTIONAL UNIT (EQUIVALENT USAGE) CONTINUES

Masters' report

The definition of the functional unit is not in accordance with the objectives of the study.

Friday's report

If the systems are not equal with regard to the time of the second change this may influence the timing of the next napkin change *after* the child has been collected by its parents and thus involve a difference in napkin consumption in the private households.

The study does not consider the trousers necessary for the reusable napkins.

FUNCTIONAL UNIT (WEIGHT)

In calculating the average weight of a napkin, the author overlooks the fact that the average napkin on the market is not equal to the average napkin used in a day nursery since the children typically do not start in the day nursery until the age of 6 months.

The comparison is based on large sized napkins rather than the average napkin used in the day nurseries (which would have been more correct).

LIMITATIONS (OMISSIONS) IN LIFE CYCLE

Water supply and waste water treatment is omitted (or forgotten?).

CHOICE OF PARAMETERS

A discussion is missing on the parameters included in the investigation and who decided what to include (e.g. welfare and economical parameters).

The report describes its objective as taking into account "all effects in the life cycle of the products."

Choice of parameters continued

Masters' report	Friday's report
Solid waste is not reported, nor is the sludge from the waste water treatment.	This is a very ambitious statement which is not balanced by a discussion on the parameters actually included in the investigation.
Consumption of resources other than fossil fuel and water are not reported. The omission of inherent energy is a serious flaw.	Consumption of resources other than energy and water are not reported.
Several parameters, e.g. surface water and drinking water appear in the evaluation without being recorded earlier.	A differentiation between hazardous and non-hazardous waste would have been desirable.

Marginal or average technology

Masters' report	Friday's report
The emissions from electricity production are based on the average national composition of the primary fuels. The emissions from electricity production are based on the average national composition of the primary fuels. Since most of the electricity-use related to the paper napkin takes place in Sweden (where little fossil fuel is used in electricity generation) this gives a strong bias in favour of the paper napkin.	The use of marginal technology (in this case coal fired power plants for electricity production) may give a correct reflection of the production system but is still a somewhat controversial approach which should not be used without explicit explanation (which is missing in Friday's report). When a methodological choice is debatable, it may be preferable to calculate the result with more than one method to show the importance of the choice.

Marginal or average technology continues

Masters' report	Friday's report
It can be argued that the production of one extra napkin (the marginal napkin) would involve an increase in fossil fuel use rather than an increase in the output from hydropower or nuclear power plants (which is the basic argument behind using marginal technology for electricity production).	
The bias is further aggravated by the assumption that emissions from hydropower and nuclear power are negligible.	

Inherent energy

Masters' report	Friday's report
If heat recovery is assumed, then the inherent energy resources in the materials should also be accounted for (they could also have been used directly for energy production).	Inherent energy is reported, but the author overlooks the (possible?) heat recovery from incineration.

Co-product allocation

Masters' report	Friday's report
	Animal manure (for cotton growing) is regarded as a waste product from animal husbandry. This means that the emissions are not included but allocated solely to the animal production. It can be discussed whether this allocation is correct since the manure has a value for the cotton production and would have to be substituted by artificial fertiliser (or green manure) if it was not available.

Data quality

Masters' report

Swiss emission data (from Habersatter & Widmer 1990) is used for electricity production. Since energy data have a relatively high importance for the final result, it would have been preferable to obtain more recent and more geographically specific data.

The emission data on PP-liner production (from Kindler & Nikles 1980) are also outdated.

Hydrocarbons are not specified but only reported as HC.

Friday's report

Presentation of data

Masters' report

Although the data are reported in an easily surveyable (matrix-) format, too much arithmetic is left to the reader: It is difficult to identify which calculations have been made to translate the data into the "total environmental effects."

The processes in the matrix do not correspond completely to the flow-charts, which makes it difficult to see whether data are missing or equals zero.

Friday's report

The data are difficult to survey, although they appear very complete. The use of a matrix structure would be preferable.

Presentation of result

Masters' report

A more visual presentation (using graphs or bar charts) would improve readability.

Evaluation

Masters' report

It is argued that the consumption of fossil fuel and emission of CO_2 should have most weight "due to their long-term and possibly irreversible effects" and that the conclusion could only be reversed "if the other emissions were an order of magnitude larger." These value judgements and expressions of relative weights does not appear adequately supported to sustain the unambiguous conclusion. It would have been preferable to have a more balanced discussion of different approaches to evaluation and their possible outcomes.

Friday's report

In the evaluation it is argued that the actual emissions of phosphorous (which is the only parameter in favour of paper napkins) are below legal emission limits. Such an exposure assessment is a reasonable procedure to qualify the effects recorded in a life cycle assessment. However, when it is made for one parameter (phosphorous) it should also be performed for the other parameters.

The evaluation does not differentiate between renewable and non-renewable energy sources.

Management of uncertainty

Masters' report

Uncertainty is reported for all figures, although mostly only as estimates based on general assumptions which are not further substantiated.

The description of the method used for sensitivity analysis is too superficial for the peer review to repeat the calculations.

Friday's report

Although the result seems clear it is not possible to judge the degree of validity of the result since uncertainty is not reported

III

To the teacher

1 Fictional reports in teaching: "Learning by discovery"

The certain way to learn about life cycle assessments is to perform one. However, when applied on its own, this philosophy of "Learning by doing" may not be the easiest nor the quickest way of learning. The task of making a life cycle assessment is so complicated that at times the student is bound feel disoriented and frustrated in the undertaking. In moderate doses, this frustration may be positive. It can focus the attention of a student on a particular problem, leading to a sense of achievement once it is overcome. In excessive doses, however, frustration may lose this motivating power, creating apathy instead. "Learning by discovery" is a way to introduce "Learning by doing" without the risk of frustration in the early phases.

"Learning by discovery" uses fictional reports to introduce the student to real life examples while avoiding the additional complexity of real life reports. Furthermore, the fictional reports are constructed to optimise the learning process. They provide the student with examples of good practice as well as the mistakes often made in real reports. Given the task of making a critical "peer review" of the reports, the student will discover the mistakes deliberately built-in and see how these affect the conclusions of the reports.

"Learning by discovery" is a method by which to introduce the topic. For students who are not going to perform life cycle assessments themselves, but merely wish to be able to read other life cycle assessments critically, the "peer review" process involving the fictional reports may be sufficient. However, for the advanced student this does not substitute "Learning by doing", i.e. the need to actually perform a life cycle assessment in order to deal with the problems themselves. Even though the student will have discovered the mistakes that others have made, this does not mean that he will not make the same mistakes when performing his own first life cycle assessment. However there is a good chance that he will discover the mistakes more easily by drawing parallels to the examples he knows intimately after having performed the "peer review process" on the fictional reports.

Obviously, course participants should have the fictional reports before the course in order to read them and prepare for the task. This will save much time and effort during the course.

2 Examples of educational settings and course plans

2.1 A three-day course

The complexity of life cycle assessment makes it difficult to teach the subject in a short time. At least three days should be allocated for the course. The following generic plan for a three-day course has been developed by UETP-EEE and has been tested in practise with successful results.

The text-book "Environmental assessment of products" publicated by UETP-EEE, as well as the "Two fictional life cycle assessments for educational purposes" should be mailed to the participants at least 14 days before the course. The textbook gives the foundations for the introductory lectures on the first day (see course plan). Chapter 5 of the textbook ("Quality criteria for life cycle assessments"), together with the work sheets in section 4 of this manual may serve as a guide for the group exercises.

Table 1. Generic plan for a three days course

1st day: Opening and presentation of participants General introduction to LCA Example of an industrial LCA (product development) Example of a public body LCA (generic product comparison) Codes of conduct Group exercise: Peer review of two LCA reports 1. session: The sections on objectives, product definition, choice of alternatives and process trees Examples of LCA's with special emphasis on the problems of system boundaries and allocation methods (e.g. an LCA from the energy sector)
2nd day: Lecture: Defining system boundaries Group exercise: Peer review of two LCA reports 2. session: The system boundaries Example of an LCA with a broad selection of parameters (working environment, social aspects) Example of an LCA with special emphasis on the evaluation method Lecture: Methods for aggregation, normalisation and evaluation Software demonstration (plenum) Break for a light dinner Software workshop: Hands-on experience guided by software experts. Presentation of further software tools
3nd day: Group exercise: Peer review of two LCA reports 3. session: The methods used for aggregation, evaluation and presentation 4. session: Data quality and sources 5. session: Sensitivity analysis Lectures/workshops on LCA for eco-design and/or qualitative methods and quick results Evaluation and conclusions

Emphasis should be placed on giving real life examples of life cycle assessments (preferably through guest lecturers from the involved enterprises, consultants or authorities) highlighting different practical aspects. Four such examples are envisaged on the first day and two the next. It is important to introduce these practical examples early in the course plan to avoid too abstract discussions in the beginning of the course. The examples should highlight the different practical aspects (system boundaries, parameter choices, evaluation method) thus illustrating the topics encountered in the following group exercise.

The group exercises all relate to the baby napkin case in "Two fictional life cycle assessments for educational purposes." Group sizes of 4-6 persons are recommended. An assistant teacher with prior knowledge of the case study should be allocated to each group. Rather than tackling the entire task at once, the groups are asked to focus on different aspects of the reports in each of the 5 group sessions:

- 1st session: Objectives, product definition, choice of alternatives and process trees. The differences between the reports in these areas are quite easy to discover, and the groups will therefore have a "soft start" to get acquainted. If time allows, the groups can also look at the material flows presented in the reports, since these also relate to the definition of the functional unit of product. This will demonstrate that all the information needed to judge an aspect may not necessarily be found under the appropriate heading (here "product definition").
- 2nd session: System boundaries. The groups should concentrate on the descriptions of the two product systems (life cycles) and look for omissions (processes or parameters) and examples of (implicit or explicit) choices of geographical and technological levels and co-product allocation.
- 3nd session: Aggregation, evaluation and presentation. The groups work on the last part of the reports, identifying and criticising the methods used in the two reports.

- 4th session: Data quality: Going back to the descriptions of the two product systems, the groups can focus on the way data are reported and the quality of individual data.
- 5th session: Sensitivity analysis. The groups may discuss different ways of making sensitivity analysis and criticise the way it is done in the two reports.

Each group session should end with a plenum presentation. The reports from each group session could be presented on flip-overs or overhead transparencies. To save time at the plenum presentation, one group only should be asked to make a full presentation, and the other groups asked to listen and add points which differ from the observations of the first group.

The software demonstration on the second day is included to introduce the participants to state-of-the-art software; its advantages and shortcomings. The participants need not to learn to use the software. Software containing the case-study data may also be used by the teacher in the plenum discussions following group sessions 3 to 5. At present the data on the baby napkin case may be obtained with the following software:

- *SimaPro*, obtainable from Pré, Bergstraat 6, NL-3811 NH Amersfoort, The Netherlands; telefax: (+31) 33 611 046,
- *PLA Educational Tool with LifeWay*, obtainable from Visionik Aps, Vendersgade 29 st.tv., DK-1363 København K., Denmark; telefax: (+45) 3313 4240.

Obviously, the data may be entered manually by the teacher in any other professional software. SimaPro also has a data export function.

The subject of the last afternoon may change depending on the nature of the course and the audience. Obvious issues to address would be improvement assessment (sensitivity analysis and feasibility assessment of the results) or application of LCA in the professional contexts of the course participants. If software is available the teacher may also lead a plenum session in which different improvement options are investigated by recombining, changing or adding data in the software.

The three-day course should give the participants a good idea of the problems involved in the life cycle assessment and enable them to read and judge life cycle assessment reports and participate in the planning phases of a life cycle assessment. To actually perform a life cycle assessment a longer course more exercise is needed.

2.2 A short course as introduction to a longer course

A short three-day course may also be used as an introduction to a longer course. In a longer course the participants should perform (parts of) a life cycle assessment themselves. If the purpose of the course is only to train the participants to participate in the planning and evaluation steps of a life cycle assessment, the actual data collection may be done by the teacher or a consultant. However the participants should at least perform the planning and evaluation steps. If the purpose of the course is to train the participants to make a life cycle assessment without the assistance of consultants, the data collection phase should also be performed by the participants.

The following course plan with three sessions have been developed by the author and have been tested with success in practice.

Table 2. Generic plan for a six days course

First course session (3 days)	
1 day	A concentrated version of the above three-day course leaving out examples other than the baby napkin case and leaving out the software demonstration.
2 days	The participants plan a life cycle assessment on a pre-selected product (preferably relating to their own professional situation). The planning takes place in a mixture of group work and plenum sessions covering the following decisions: Objectives, product definition, system boundaries, choice of parameters, evaluation method. The planning ends in a plenum session agreeing on a common data collection strategy: Which data are most important to collect?
Between first and second course session	
	The teacher or a consultant collects the data in accordance with the data collection strategy specified by the course participants. A minimum of two weeks should be allocated for this task.
Second course session (1 day)	
1 day	The result of the data collection is presented and discussed. A preliminary evaluation is performed and the result discussed. Based on this experience, the data collection strategy is revised or elaborated.
Between second and third course session	
	The teacher or the consultant continues the data collection. Another two weeks should be allocated for this task (minimum).
Third course session (3 days)	
1 day	The revised result of the data collection is presented and discussed. Evaluation is performed and the result discussed. The entire course experience up to this point is evaluated.
2 days	The participants plan a life cycle assessment on a product system of their own choice. The planning includes: Objectives, product definition, system boundaries, choice of parameters, evaluation method and data collection strategy. The purpose of the 2 days is to test the skills obtained by the participants and to illustrate that different life cycle assessments may need quite different approaches and quite different problems may be encountered.

The above course concept has been planned for participants who are not going to perform data collection themselves. However, the course may be extended to include the participants own data collection (under guidance of the teacher) and a session in which the results are evaluated, presented and discussed. In the course below the participants collect the data themselves from the start which demands some more preparation, since the participants must be familiar with the necessary computer software and the problems which may be encountered during data collection:

Table 3. Generic plan of a seven days course with data collection

First course session (5 days)	
1 day	A concentrated version of the above three-day course leaving out examples other than the baby napkin case and leaving out the software demonstration.
2nd day	Exercises with software; hands-on-experience.
3rd day	Choosing a product system for case study
4th day	Planning the life cycle assessment in a mixture of group work and plenum sessions covering the following decisions: Objectives, product definition, system boundaries, choice of parameters, evaluation method, data collection strategy.
5th day	Discussion of the problems which may be encountered during data collection.
Between first and second course session	
	The participants collect the data in accordance with their data collection strategy. The collected data are entered into the computer software. The teacher should be available for telephone consultation. A minimum of four weeks should be allocated for this task.
Second course session	
1 day	In groups, the participants discuss the problems encountered in data collection and in the use of software.
2 nd day	The groups present cases and experiences of common interest for plenum discussion. Course evaluation.

For this course it is essential that the participants have access to a computer, both during and between the course sessions. One computer per person is

necessary. For the initial computer exercises the baby napkin case may be used. The participants may be asked to take the best methodology and the best data from each report and make a completely new report for which they must calculate the results themselves.

2.3 A university semester course

University courses are most often spread out in time and consist of a mixture of lectures and exercises. For this purpose, the 5 sessions of the three-day course may be regarded as separate exercises. If time allows, the students should be asked to report their findings in writing. The reports from the five sessions could be gathered into one report which would then be a complete peer review of the two fictional baby napkin studies, resembling the example answer in section 5. of this teacher's manual.

The lectures should be arranged so that they relate to the exercises. Lectures should be a mixture of theory and practical examples illustrating the subject.

The peer review exercises may be followed by computer exercises and a set of activities in which the students plan a life cycle assessment on a product system of their own choice (or chosen by the teacher). Each of the planning phases (objectives, product definition, system boundaries, choice of parameters, evaluation method, data collection strategy) may be regarded as separate exercises even though they are performed on the same product system.

If reguired, the students could continue, the following semester, with an advanced course in which they carry out the data collection prepared in the first course. The collected data would then be used in an evaluation phase and presented in a full report on the life cycle assessment performed.

2.4 Self-tuition

The two fictional reports may also be used for self-tuition. The work sheets in section 4. of this teacher's manual may be of help in performing the peer review. Also, chapters 4 and 5 of the textbook "*Environmental Assessment of Products*" should be consulted. The example answer (Section 5. in this teacher's manual) may be used as a control *after* having performed the peer review but should not be consulted until the peer review has been completed.

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