REPORT

Life cycle assessment of premium single-use and reusable napkins for restaurant dinners

For Duni AB

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About the critical review

This version of the report was reviewed by a third party. The full Critical Review Report is available as Appendix F.

1. Introduction

Customers and professional users are increasingly asking for the environmental performance of products. Ambitions within a company to provide products of high environmental performance are also a driver for performing detailed environmental assessments. A life cycle assessment (LCA) of products or services is a useful tool in obtaining quantified environmental information, providing a basis for further product development as well as a support for a dialogue with stakeholders regarding environmental issues.

On the commission of Duni AB, IVL Swedish Environmental Research Institute has performed a comparative LCA of premium single-use and reusable table napkins. The study has taken place between December 2009 and June 2010 using data from 2009 for the production and converting of paper. The report underwent an external review from July to October 2011.

The goal of the study was to calculate the environmental impact (in terms of four impact categories used in the International EPD System) of Duni single-use napkins and to compare their performance with that of reusable textile napkins of cotton and linen (made from flax fibres) based on literature and database data. The study focused on usage at restaurants at three markets, and the single-use napkins were modelled in such a way to simplify the process of creating certified environmental product declarations (EPD).

Single-use and reusable products have been compared with LCA methodology in the past, but in the initial literature review it was concluded that there were no publicly available full LCA studies that compare paper napkins with reusable alternatives. A simple carbon footprint calculation using some of the elements from a life cycle assessment is available through Treehugger (Paster, 2009). The conclusion of this calculation is that for the American market, the greenhouse gas emissions of the paper napkin are lower than those of the reusable napkin for the restaurant scenario, but higher for the home scenario. The results of the present study should be highly interesting since it uses the full life cycle perspective for multiple environmental impact categories and presents results for three different European markets.

The format of this report has been adjusted to the target audience. The different phases of a life cycle assessment according to ISO (2006) correspond to the following chapters:

- **Goal and scope**: Appendix A, with a summary in Section 2.
- **Life cycle inventory analysis**: Appendix B
- **Life cycle impact assessment**: Section 3, with additional results in Appendix D.
- **Interpretation**: Appendix D, with a summary in Section 14

The study has been performed in accordance with the international standard of life cycle assessment, ISO 14044. (ISO, 2006). In its current version, the ISO standard requires a review by a panel of interested parties (three persons) for studies that include "comparative assertions" to the public. As this report has been reviewed by only one independent external reviewer, the ISO standard is no longer followed if used to support such "comparative assertions" to the public.

2. Overview of goal and scope

This section provides an overview of the methodology used in this study. Detailed information on the methodology is available in Appendix A, while data collection is described in Appendix B.

The goal of this study is to calculate the environmental impact (in terms of four impact categories used in the International EPD System[1]) of Duni single-use napkins and to compare their performance with that of reusable textile napkins of cotton and linen[2] based on literature and database data; see Table 1. The napkins produced by Duni are based on actual products, while the two reusable napkins are estimated alternatives based on available product samples and data from literature. All napkins are modelled as white and without print.

The investigated markets are restaurants in Germany, Sweden and the United Kingdom. The product specifications and production are the same for the different markets. What differs is the difference in transport distance from converting to an average customer, the country-average electricity mix used during washing and the waste management scheme.

No manufacturer of reusable napkins has been involved in the study. As an attempt to avoid overestimations of the environmental impacts from these products, conservative assumptions have been made where possible and important assumptions have been checked in the sensitivity analysis.

Table 1: The table napkins investigated in this study, including information on the data source for the product specifications. All napkins are of "premium" type used at restaurants, why no 1 or 2-ply (layers) napkins used at cafeterias have been included.

	Type	Grammage (g/m^2)	Weight (g)	Size (cm x cm)	Data source
Duni tissue napkin	Single-use	45 (3 layers)	7.2	40x40	Duni (actual product)
Dunilin	Single-use	71	11.6	40.5x40.5	Duni (actual product)
Dunicel	Single-use	140	23.5	41x41	Duni (actual product)
Cotton napkin	Reusable	200	42.3	45x45 (46x46*)	Theoretical, based on samples & literature
Linen napkin	Reusable	220	46.6	45x45 (46x46*)	Theoretical, based on samples & literature

* To calculate the total weight of the napkin, it was assumed that the sides were folded by 0.5 cm per edge.

The difference in size between paper napkins and reusable alternatives is consistent with actual conditions, where paper napkins are usually around 40x40 square centimetres while textile napkins are a bit larger. The functional unit was chosen as "one use of a dinner napkin at an average restaurant" at three markets selected by Duni: Germany, Sweden and the United Kingdom.[3] The results are presented separately for each market.

The study covers the entire life cycle of the products, from forestry or cultivation of cotton and flax to waste management of used products. The boundary between nature and the product life cycle is

[1] Climate change, acidification, eutrophication and photochemical oxidant formation. See Appendix A.

[2] Linen is here defined as the material made from the flax fibre.

[3] The functional unit is the basis of comparison between different product systems in an LCA.

crossed when materials, such as crude oil, are extracted from the ground and when emissions occur to soil, air or water. Direct and indirect effects due to land use change have not been included due to uncertainty in data.

The potential environmental impacts of the systems are calculated in four categories: climate change, acidification, eutrophication and photochemical oxidant creation. These are the same environmental impact categories that are included in the International EPD System, with the exception of stratospheric ozone depletion potential (SEMCo, 2008b). One should, however, be aware that other impact categories may be relevant for a full environmental assessment of these products. The results are presented in absolute values divided into six life cycle stages as well as relative to the Duni tissue napkin.

The system boundary and life cycle stages for single-use napkins of paper are shown in Figure 1.

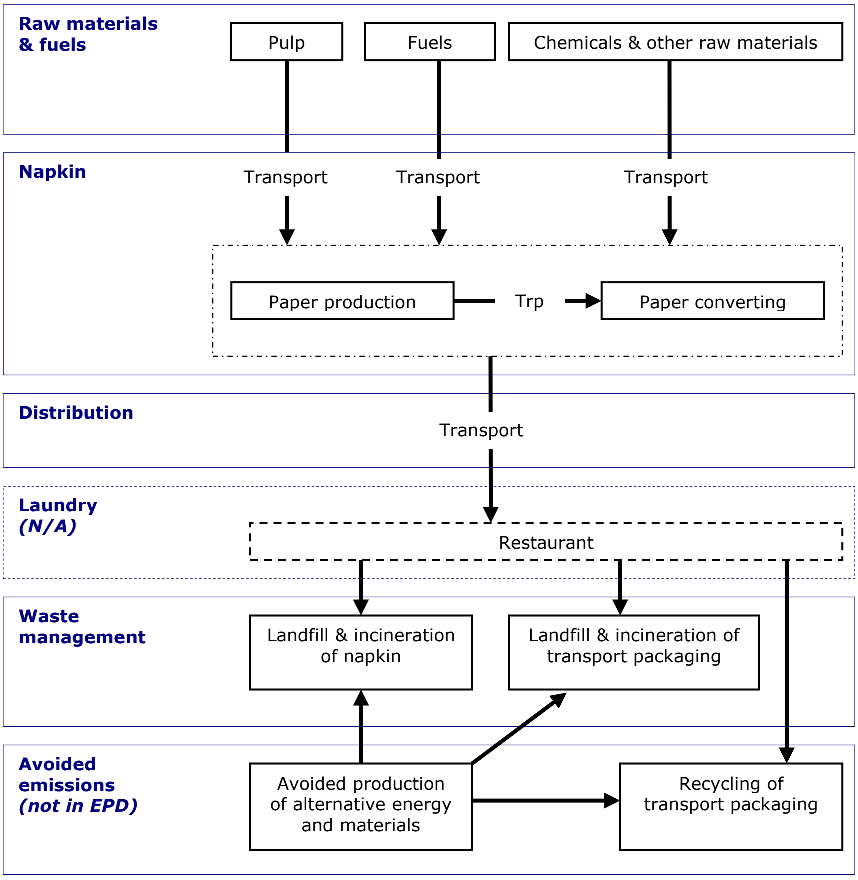

Figure 1 System boundary and life cycle stages for the single-use napkin – Duni tissue napkin, Dunilin and Dunicel

For the Duni napkins, the main raw material is virgin pulp. The pulp is used to produce tissue or Airlaid paper in Sweden and then transported to a converting site in Germany. This part of the life cycle is identical for all three markets. After converting, the napkins were distributed to each market by truck and train and used at an average restaurant.

After use, the paper napkins were assumed to be collected together with the mixed municipal solid waste at each market. The waste management scheme varies between the markets: mainly incineration in Sweden and Germany, and mainly landfilling in the United Kingdom.

The system boundary and life cycle stages for the reusable napkins are shown in Figure 2.

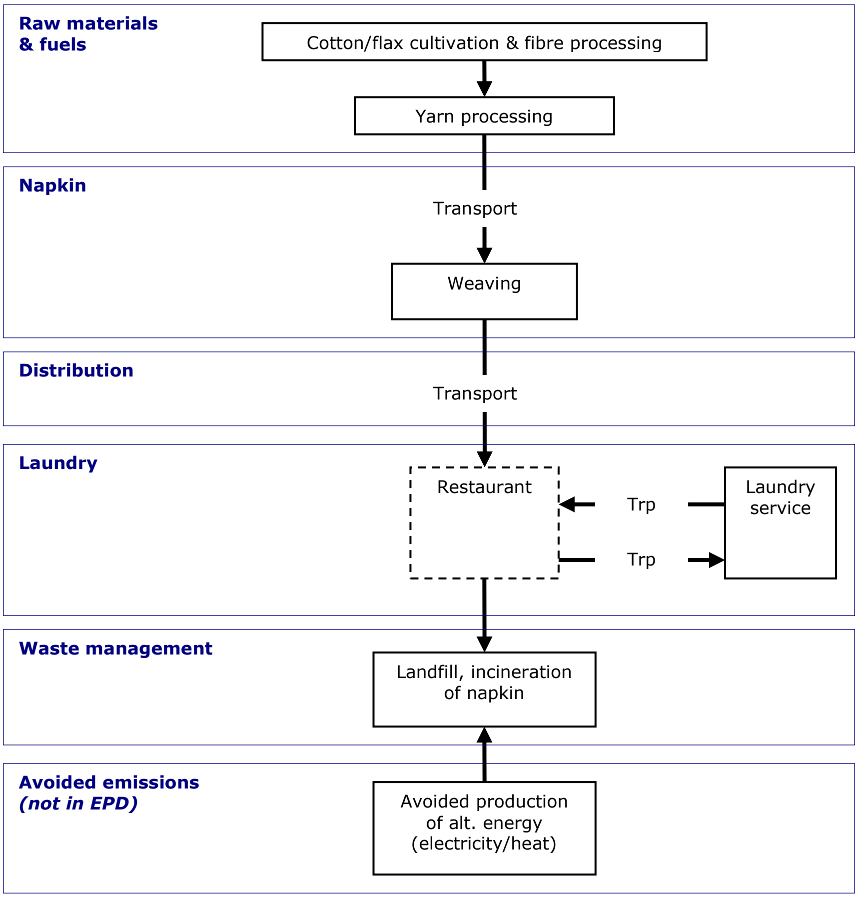

Figure 2 System boundary and life cycle stages for the reusable napkins – cotton napkin and linen napkin.

Cotton cultivation and fibre processing was assumed to take place in the United States and in China. Flax cultivation and fibre processing was assumed to take place in Benelux, using a French electricity mix. Weaving of the napkins was assumed to take place in Europe. This part of the life cycle is identical for all three markets. The napkins are then distributed to one each market by truck.

The reusable napkins were assumed to be washed 40 times during its life cycle, why only 1/40 of the material of a napkin was attributed to each napkin use. After being used 40 times, the textile napkins were assumed to be discarded and collected together with the mixed municipal solid waste at each market. The output water from laundry was assumed to be handled in a medium-sized municipal waste water treatment plant.

The life cycle stage "avoided emissions" has been included for both single-use and reusable napkins to account for the electricity, heat and material that are generated during waste management. This energy or material is assumed to replace alternative production of the same commodity and this alternative production is subtracted to the total impact of the napkin systems. This life cycle stage is generally not included in the International EPD System and should therefore be removed to be able to use the results in an EPD.

3. Results

This section shows the main results of the study. The results are presented separately for the three end-user markets: Germany, Sweden and the United Kingdom. The results divided into life cycle stages of acidification and photochemical oxidant creation potential are presented in Appendix C.

All results are calculated per functional unit – "one use of a dinner napkin at an average restaurant" – and thus the washing and reuse of textile napkins is accounted for.

3.1. Results for use on the German market

3.1.1. All impact categories, relative to Duni tissue napkin

The results for all napkin systems on the German market are presented in Figure 3. The results have been calculated as relative to the Duni tissue napkin, i.e. the result of Duni tissue napkin has been set to 1 (100%) in each impact category.

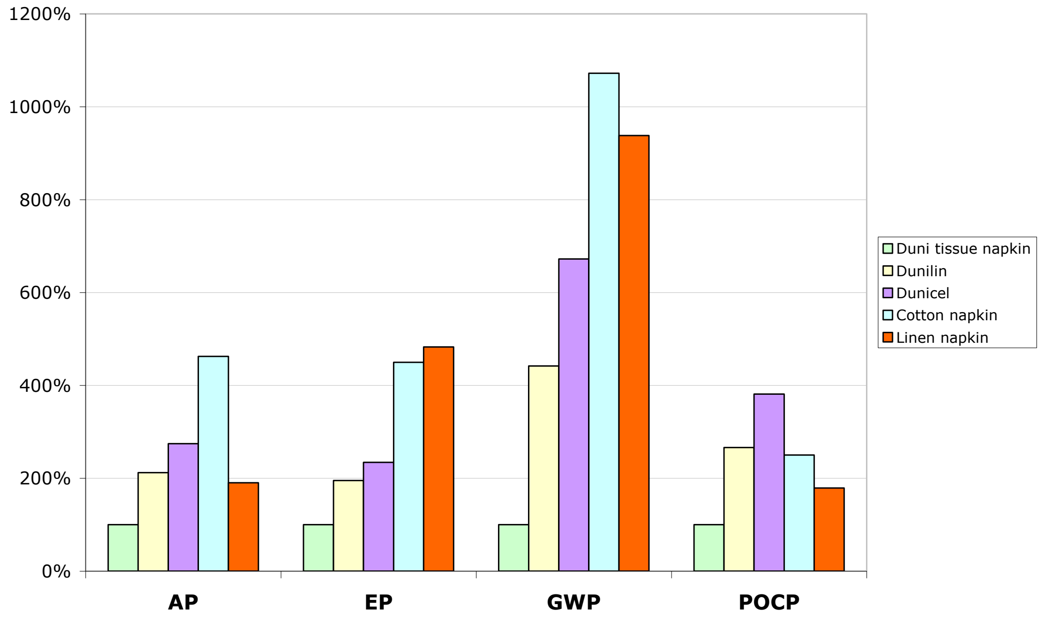

Figure 3 Environmental impacts of the five napkin systems on the German market relative to the Duni tissue napkin. The result for Duni tissue napkin has been set to 1 (100%) in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the Duni tissue napkin has the lowest environmental impacts on the German market for all impact categories included in this study.

The total impact of the paper napkins roughly follows the weight of the napkins in all impact categories: the Duni tissue napkin has a lower impact than Dunilin, which in turn has a lower impact than Dunicel. For EP (eutrophication potential) and GWP (global warming potential), all paper napkins have a lower impact than the textile napkins. For AP (acidification potential), Dunilin and Dunicel have a lower impact than the cotton napkin but higher impact than the linen napkin. For POCP (photochemical oxidant creation potential), they have an equal or higher impact than the two reusable napkins.

Of the reusable napkins, it is the linen napkin that has the lowest environmental impacts for AP; GWP and POCP. The results for EP are quite similar for the two reusable napkins, although somewhat lower for the cotton napkin.

The impact category with the largest difference between Duni tissue napkin and the napkin with the highest impact is GWP, where the difference is about a factor of eleven. Dunicel, the cotton napkin and the linen napkin are each the napkin with the highest impact in at least one impact category.

3.1.2. Climate change and eutrophication

This section presents the results for global warming potential (GWP) and eutrophication divided into the six life cycle stages: Raw materials & energy, Napkin, Distribution, Laundry, Waste management and Avoided emissions.

The results for global warming potential when the napkins are used on the German market are presented in Figure 4.

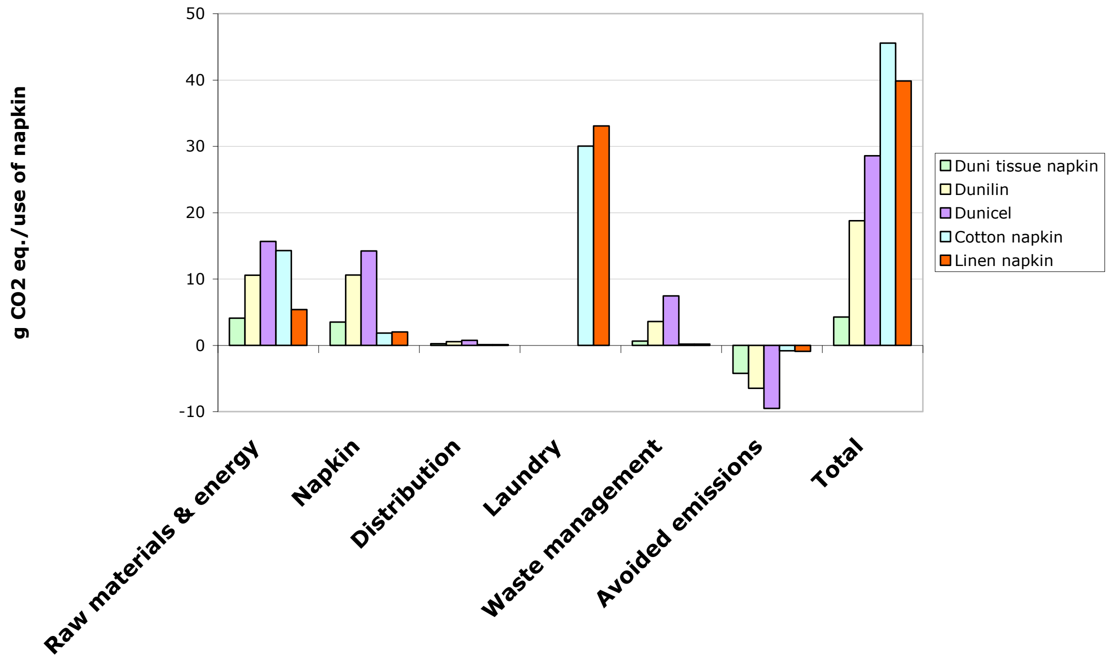

Figure 4 Global warming potential for the five napkin systems on the German market (unit: g CO_2e/use of napkin).

As the results show when divided per life cycle stage, the emissions of greenhouse gases for raw material and energy and for napkin production vary greatly between the paper napkins, but follow roughly the weight of the napkins. The Duni tissue napkin has a lower impact than Dunilin, which in turn has a lower impact than Dunicel.

The contribution of the distribution transport is small for all napkins compared to the other life cycle stages. Waste management is also minor for most napkins, where the exceptions are Dunilin and Dunicel. This is due to the content of glue in both these napkins.

For reusable napkins, the laundry is by far the most important life cycle stage for emissions of greenhouse gases. This is caused by the use of natural gas and electricity at the laundry facility. For raw materials, there is a large difference between the two textile napkins. This is mainly due to the assumption that flax cultivation and processing takes place in France – a country with a low-carbon electricity mix – while cotton cultivation and processing was assumed to take place in China and the United States, where the electricity mix is more dependent on fossil fuels.

To contrast these results, the results in eutrophication potential are plotted in Figure 5.

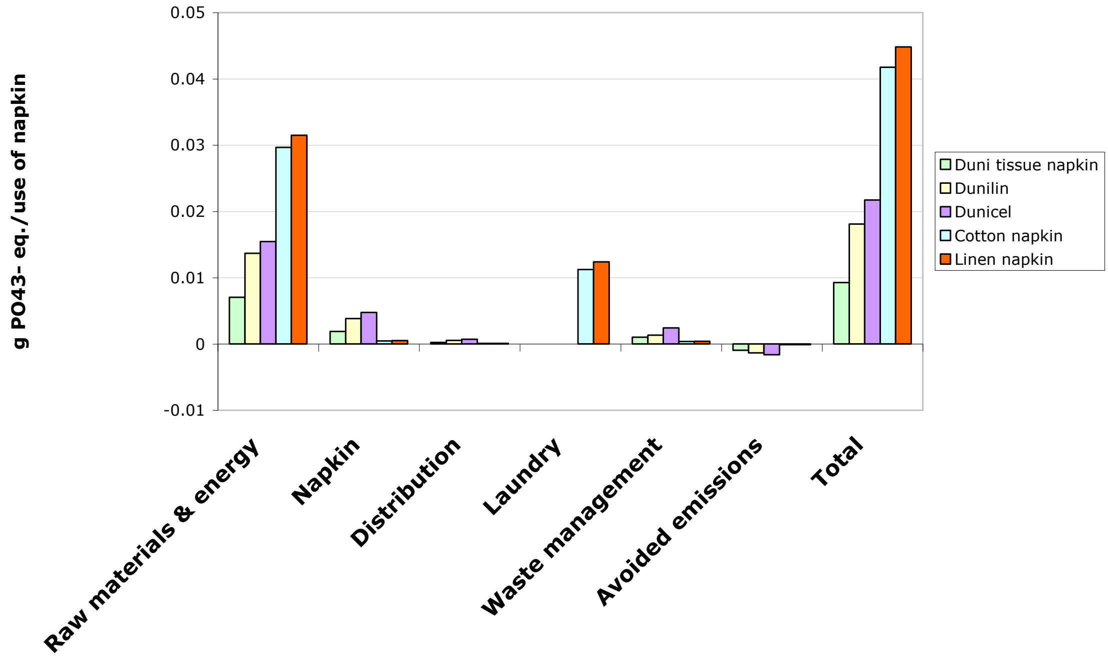

Figure 5 Eutrophication potential for the five napkin systems on the German market (unit: g PO_4^{3-}e/use of napkin).

For the paper napkins, the production of raw material and energy is very dominant in terms of eutrophication potential. This is due to the fact that the emissions of eutrophying substances are connected to forestry and pulp production, and not as much to the combustion of fossil fuels as GWP.

For reusable napkins, the production of raw materials and energy is the most important life cycle stage. The emissions of eutrophying substances are in the same order of magnitude for the two napkins in this life cycle stage. This is quite different from GWP, and is caused by the fact that eutrophication is not as dependent on what type of electricity is used as GWP.

For the reusable napkins, the emissions from the laundry are also significant. These emissions are caused by the production of electricity used for washing as well as the emissions of eutrophying substances to water that are not handled by the waste water treatment plant.

3.2. Results for use on the Swedish market

3.2.1. All impact categories, relative to Duni tissue napkin

The results for all napkin systems on the Swedish market are presented in Figure 6. The results have been calculated as relative to the Duni tissue napkin, i.e. the result of Duni tissue napkin has been set to 1 (100%) in each impact category.

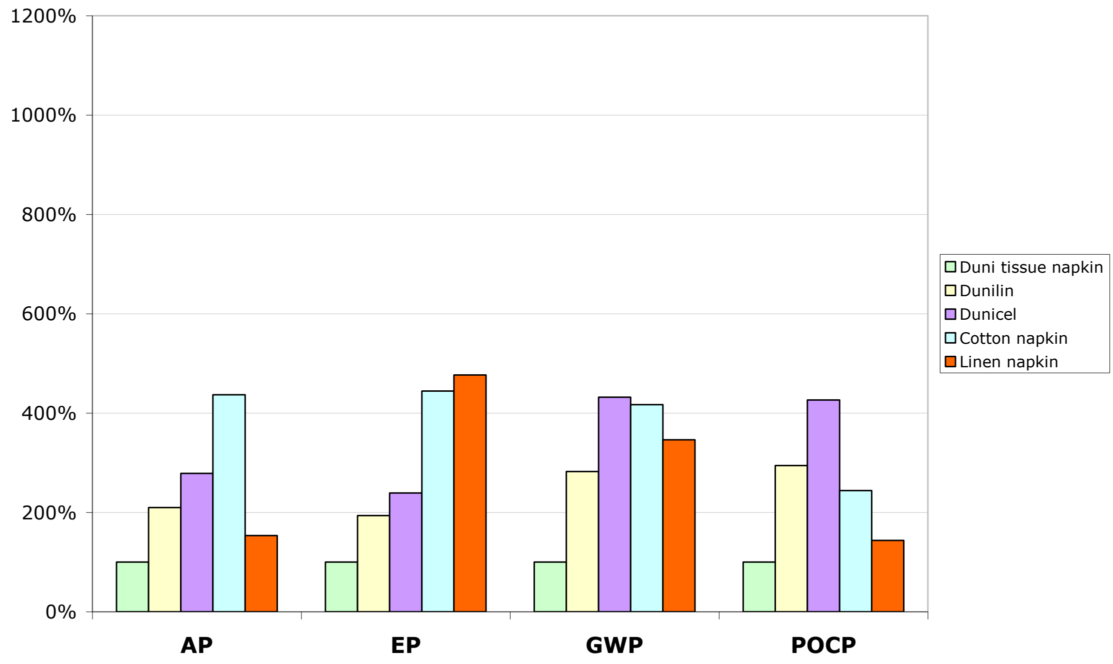

Figure 6 Environmental impacts of the five napkin systems on the Swedish market relative to the Duni tissue napkin. The result for Duni tissue napkin has been set to 1 (100%) in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the Duni tissue napkin has the lowest environmental impacts on the Swedish market for all impact categories included in this study.

The total impact of the paper napkins roughly follows the weight of the napkins in all impact categories: the Duni tissue napkin has a lower impact than Dunilin, which in turn has a lower impact than Dunicel. For EP (eutrophication potential), all paper napkins have a lower impact than the textile napkins. For AP (acidification potential), Dunilin and Dunicel have a lower impact than the cotton napkin but higher than the linen napkin. For POCP (photochemical oxidant creation potential), they have a higher impact than the two reusable napkins.

Of the reusable napkins, it is the linen napkin that has the lowest environmental impacts for AP; GWP (global warming potential) and POCP. The results for EP are quite similar for the two reusable napkins, although somewhat lower for the cotton napkin

The relative impact between Duni tissue napkin and the napkin with the highest impact is about the same for all impact categories (about four). Dunicel, the cotton napkin and the linen napkin are each the napkin with the highest impact in at least one impact category.

3.2.2. Climate change and eutrophication

This section presents the results for global warming potential (GWP) and eutrophication divided into the six life cycle stages: Raw materials & energy, Napkin, Distribution, Laundry, Waste management and Avoided emissions.

The results for global warming potential when the napkins are used on the Swedish market are presented in Figure 7.

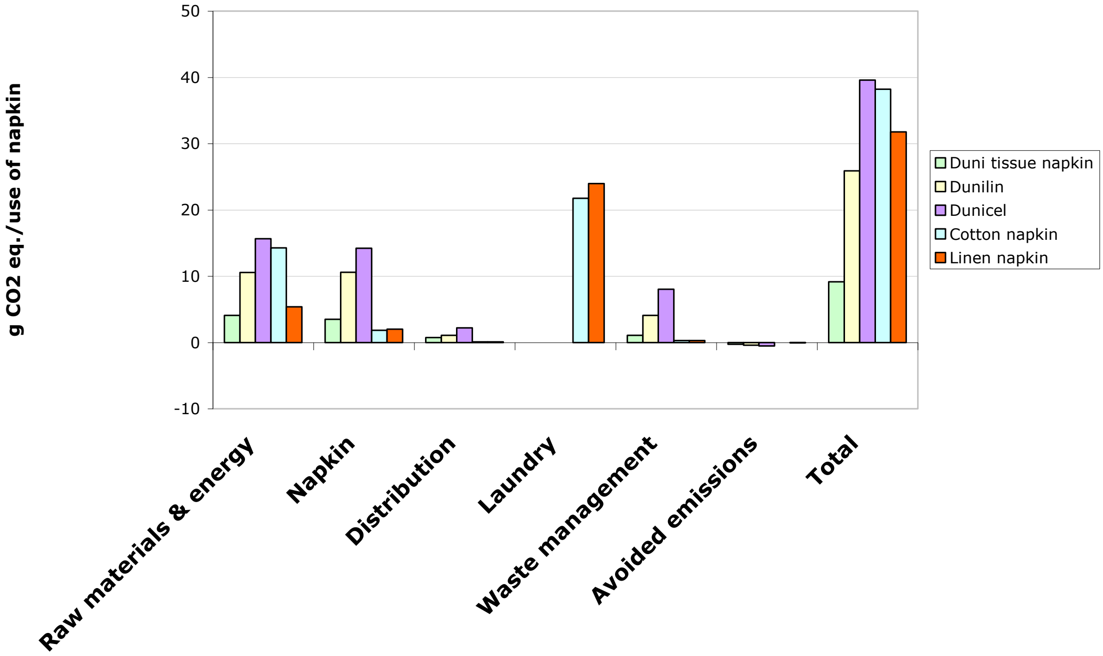

Figure 7 Global warming potential for the five napkin systems on the Swedish market (unit: g CO_2e/use of napkin).

As the results show when divided per life cycle stage, the emissions of greenhouse gases for raw material and energy varies greatly between the paper napkins but follow roughly the weight of the napkins. The Duni tissue napkin has a lower impact than Dunilin, which in turn has a lower impact than Dunicel.

The contribution of the distribution transport is small for all napkins compared to the other life cycle stages. Waste management is also minor for most napkins, where the exceptions are Dunilin and Dunicel. This is due to the content of glue in both these napkins.

For reusable napkins, the laundry is by far the most important life cycle stage for emissions of greenhouse gases. This is caused by the use of natural gas and electricity at the laundry facility. For raw materials, there is a large difference between the two textile napkins. This is mainly due to the assumption that flax cultivation and processing takes place in France – a country with a low-carbon electricity mix – while cotton cultivation and processing was assumed to take place in China and the United States, where the electricity mix is more dependent on fossil fuels.

To contrast these results, the results in eutrophication potential are plotted in Figure 8.

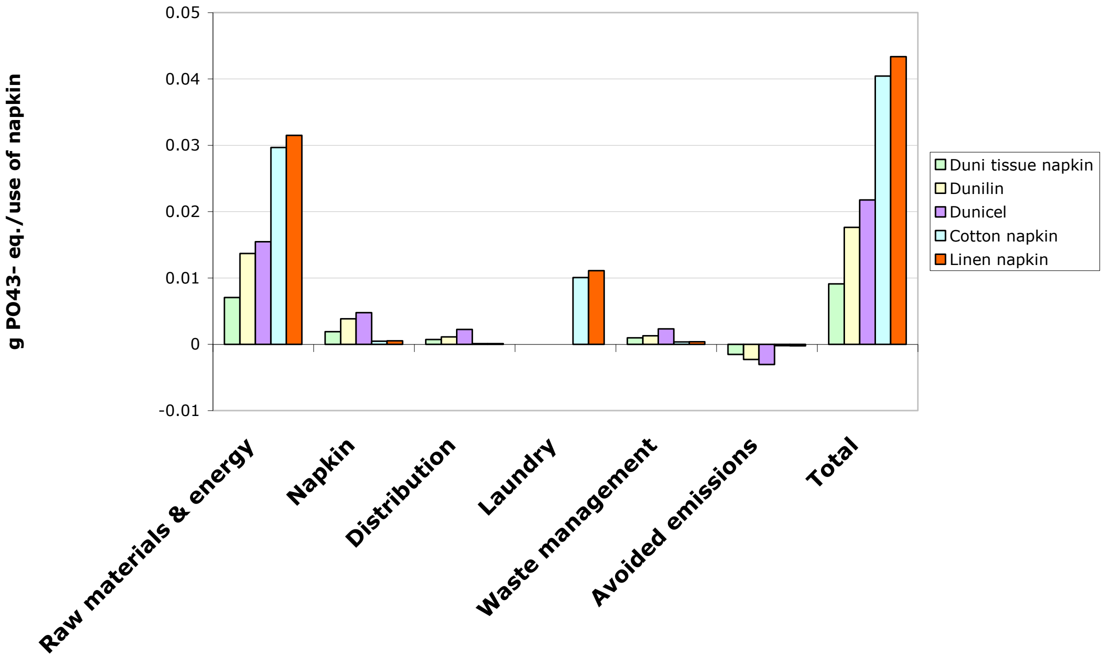

Figure 8 Eutrophication potential for the five napkin systems on the Swedish market (unit: g PO_4^{3-}e/use of napkin).

For the paper napkins, the production of raw material and energy is very dominant in terms of eutrophication potential. This is due to the fact that emissions of eutrophying substances are connected to forestry and pulp production, and not as much to the combustion of fossil fuels as GWP.

For reusable napkins, the production of raw materials and energy is the most important life cycle stage. The emissions of eutrophying substances are in the same order of magnitude for the two napkins in this life cycle stage. This is quite different from GWP, and is caused by the fact that eutrophication is not as dependent on what type of electricity is used as GWP.

For the reusable napkins, the emissions from the laundry are also significant. They are caused by the production of electricity used for washing as well as the emissions of eutrophying substances to water that are not handled by the waste water treatment plant.

3.3. Results for use on the British market

3.3.1. All impact categories, relative to Duni tissue napkin

The results for all napkin systems on the British market are presented in Figure 9. The results have been calculated as relative to the Duni tissue napkin, i.e. the result of Duni tissue napkin has been set to 1 (100%) in each impact category.

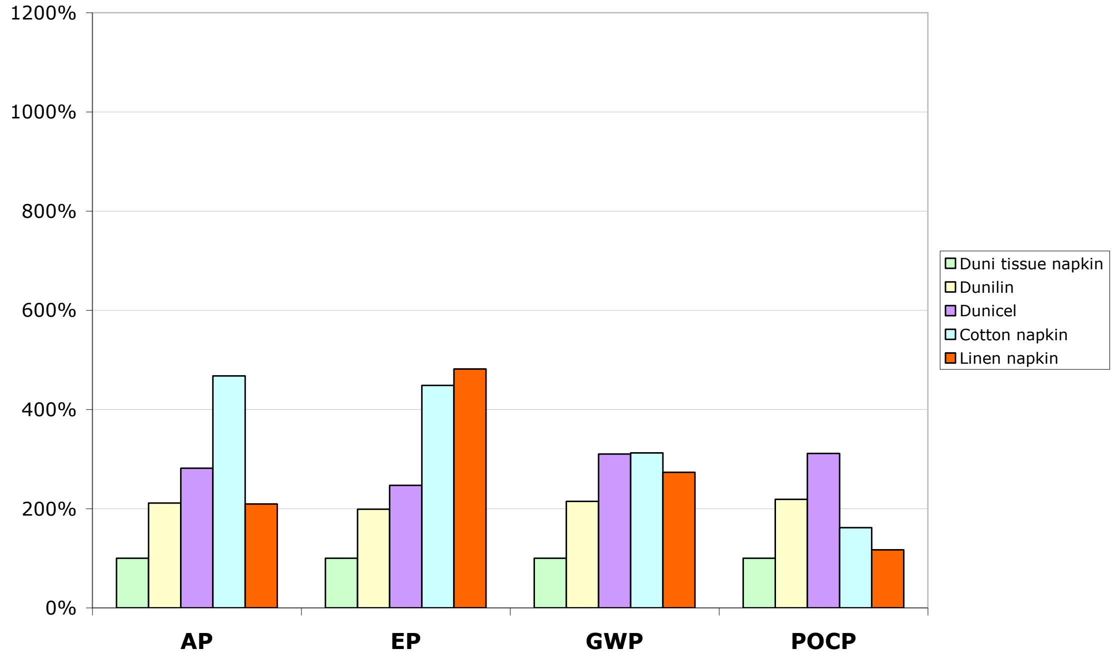

Figure 9 Environmental impacts of the five napkin systems on the British market relative to the Duni tissue napkin. The result for Duni tissue napkin has been set to 1 (100%) in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the Duni tissue napkin has the lowest environmental impacts on the British market for all impact categories included in this study.

The total impact of the paper napkins roughly follows the weight of the napkins in all impact categories: the Duni tissue napkin has a lower impact than Dunilin, which in turn has a lower impact than Dunicel. For EP (eutrophication potential), all paper napkins have a lower impact than the textile napkins. For AP (acidification potential), Dunilin and Dunicel have a lower impact than the cotton napkin but higher than or equal to the linen napkin. For POCP (photochemical oxidant creation potential), they have a higher impact than the two reusable napkins.

Of the reusable napkins, it is the linen napkin that has the lowest environmental impacts for AP; GWP (global warming potential) and POCP. The results for EP are quite similar for the two reusable napkins, although somewhat lower for the cotton napkin.

The relative impact between Duni tissue napkin and the napkin with the highest impact is about three to four for all impact categories. Dunicel, the cotton napkin and the linen napkin are each the napkin with the highest impact in at least one impact category.

3.3.2. Climate change and eutrophication

This section presents the results for global warming potential (GWP) and eutrophication divided into the six life cycle stages: Raw materials & energy, Napkin, Distribution, Laundry, Waste management and Avoided emissions.

The results for global warming potential when the napkins are used on the German market are presented in Figure 10.

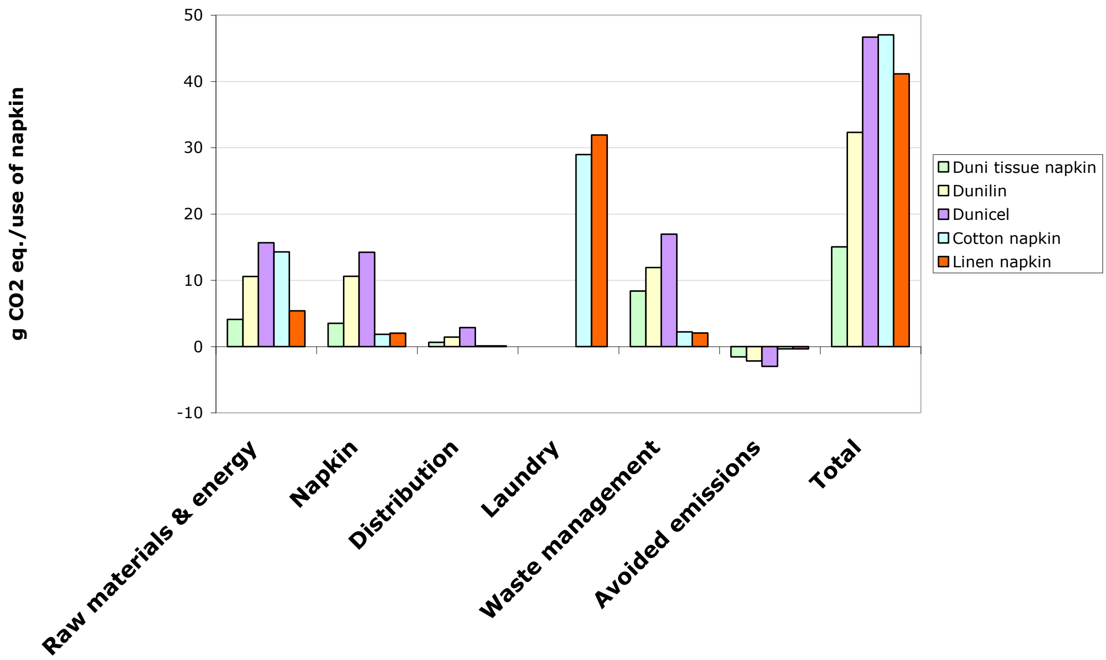

Figure 10 Global warming potential for the five napkin systems on the British market (unit: g CO_2e/use of napkin).

As the results show when divided per life cycle stage the emissions of greenhouse gases for raw material and energy varies greatly between the paper napkins, but follow roughly the weight of the napkins. The Duni tissue napkin has a lower impact than Dunilin, which in turn has a lower impact than Dunicel.

The contribution of the distribution transport is small for all napkins compared to the other life cycle stages. Waste management is significant for the paper napkins used on the British market due to the emissions of methane when organic material is decomposed at landfill. In the UK, much more waste is disposed of at landfill compared to Germany and Sweden, where the primary treatment method of municipal solid waste is incineration.

For reusable napkins, the laundry is the most important life cycle stage for emissions of greenhouse gases. This is caused by the use of natural gas and electricity at the laundry facility. For raw materials, there is a large difference between the two textile napkins. This is mainly due to the assumption that flax cultivation and processing takes place in France – a country with a low-carbon electricity mix – while cotton cultivation and processing was assumed to take place in China and the United States, where the electricity mix is more dependent on fossil fuels.

To contrast these results, the results in eutrophication potential (EP) are plotted in Figure 11.

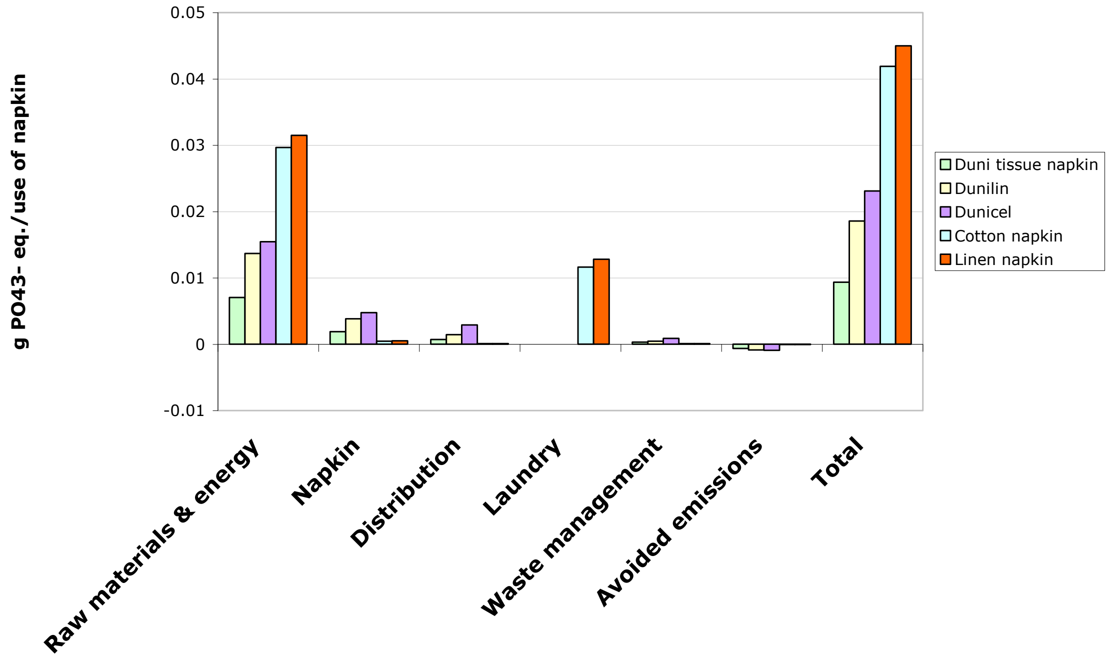

Figure 11 Eutrophication potential for the five napkin systems on the British market (unit: g PO_4^{3-}e/use of napkin).

For the paper napkins, the production of raw material and energy is very dominant in terms of eutrophication potential. This is due to the fact that emissions of eutrophying substances are connected to forestry and pulp production, and not as much to the combustion of fossil fuels as GWP.

For reusable napkins, the production of raw materials and energy is the most important life cycle stage. The emissions of eutrophying substances are in the same order of magnitude for the two napkins in this life cycle stage. This is quite different from GWP, and is caused by the fact that eutrophication is not as dependent on what type of electricity is used as GWP.

For the reusable napkins, the emissions from the laundry are also significant. These emissions are caused by the production of electricity used for washing as well as the emissions of eutrophying substances to water that are not handled by the waste water treatment plant.

4. Interpretation of results and discussion

This study has calculated the environmental impacts of different napkin options from a life cycle perspective. The results are analysed and interpreted in detail in Appendix D.

When interpreting the results, the goal and scope should always be considered. In this case the goal was to calculate the environmental impact (in terms of four impact categories used in the International EPD System) of Duni single-use napkins and to compare their performance with that of reusable textile napkins of cotton and linen (made from flax fibres) based on literature and database data. The single-use napkins were modelled in such a way to simplify the process of creating a certified environmental product declaration (EPD).

The study thus answers the question "what environmental impacts may be attributed to the use of a napkin?" Like all sets of LCA methodologies, the general requirements of the International EPD System have its limitations as a reference for the system boundary, included impact categories and other methodological choices. It was chosen anyway for its transparency, international accessibility and applicability if Duni would like to proceed with EPDs of their products in the future.

In order for the attributed impact of different napkins to be comparable, they must have a consistent system boundary and methodology. A potential problem in this regard may be that the Duni napkins benefit from using site-specific data on electricity, etc., while alternative products don't have this advantage as they are based on market averages. This does not only affect the production, but other life cycle stages as well. The sensitivity analysis shows that the assumption on electricity mix used at laundry had a quite large impact on the results for global warming potential for the reusable napkins, but not for the other impact categories.

The functional unit (the unit serving as the basis of comparison) must also be consistent between different systems for the systems to be comparable. In this study, the functional "one use of a dinner napkin at an average restaurant" was used: The underlying assumptions are that the material type and napkin size do not make any difference for providing this function, and that only one napkin is used per seating. In the base case it was assumed that the paper napkins had an area of about 40x40 square centimetres, while the reusable napkins were larger, and thus heavier. This is based on actual conditions, but could potentially be considered unfair to the reusable napkins. As shown in the sensitivity analysis, this assumption could have a large effect on the results.

The study covers four environmental impact categories that represent diverse set of impacts, covering many relevant emissions and giving different results, but they are not a comprehensive set. Some environmental impacts that are not covered by these impact categories are stratospheric ozone depletion, loss of biodiversity, toxicity (human and ecological), land use and water scarcity. Especially cotton – as a result of it being very common crop – has been much debated in terms of water stress, pesticide use, etc. (see for instance Kooistra and Termorshuizen, 2006; Cherret et al, 2005 and Naturskyddsföreningen, 2007). Methodologies for including these impacts in an LCA are under development, and could potentially be an area where this study could be expanded.

Another aspect to keep in mind when interpreting the results is what activities and related emissions are in the control of Duni. The results differ between the three markets due to different transport distances, electricity mix and waste management system. The two latter are not in the control of Duni, but could be affected through industry associations to promote cleaner energy production and a waste management system with a lower environmental impact (from a systems' perspective).

5. Conclusions, limitations and recommendations

The study has calculated and presented the environmental impacts that can be attributed to the life cycle and use of five different white table napkins at an average restaurant. No manufacturer of reusable napkins has been involved in this study, why sensitivity analyses were performed on key assumptions such as the size of the reusable napkins and the number of times a reusable napkin is washed during its life time.

The study has considered potential environmental impacts in terms of global warming, acidification, eutrophication and photochemical oxidant creation, but not other impact categories. Based on the study results, these are the main conclusions:

- The results of the study cannot be used to support general statements regarding the environmental superiority of either the product group "single-use napkins" or the product group "reusable napkins". The results and the sensitivity analyses have shown that the results of this comparison depends on the type of napkin product, the size of the napkin, the type of textile used in reusable napkins and what environmental impact category is considered most important by the reader.
- In the base case, the Duni tissue napkin has the lowest environmental impacts of the studied napkin systems for the environmental impact categories considered in this study and for all three markets. The low weight (7.2 grams) compared to the alternatives is a key aspect. When using all best case assumptions for the reusable napkins, the Duni tissue napkin is still an option with low relative impact, but the impact of the linen napkin is also low for acidification and for photochemical oxidant creation.
- The linen napkin cause lower environmental impacts than the cotton napkin for three out of four impacts categories in the base case. Some of this difference may be attributed to the fact that flax was assumed to be cultivated in France, while cotton was assumed to be cultivated in China and the United States. For some environmental impact categories and markets, such as acidification potential and photochemical oxidant creation potential on the Swedish market, the impact of the linen napkin is almost as low as for the Duni tissue napkin in the base case. In practice many reusable napkins are a combination of linen and cotton. Such a product has not been included here, but its environmental impact would likely be somewhere in between the 100% cotton and the 100% linen napkins.
- The three markets show almost the same result in terms of how the napkins are ranked in each individual impact category in the base case. The results are, however, sensitive to the assumptions regarding napkin size and to the number of wash cycles for reusable napkins. The global warming impact category is also sensitive to if electricity from renewable sources is used for the laundry service.
- Assuming hard coal as the source of electricity throughout the product system ("marginal electricity") changes the results in terms of global warming potential. This is particularly evident in three cases: the electricity mix for flax processing, the production of paper napkins and the laundry of textile napkins. Using a consequential LCA approach instead of the attributional LCA approach that was used in the base case could affect the conclusions of the study.
- In the base case, three of the five napkins may be identified as the napkin with the highest environmental impact for at least one combination of market and impact category, e.g.

Dunicel (photochemical oxidant creation potential on all markets), the cotton napkin (acidification potential on all markets) and the linen napkin (eutrophication potential on all markets).

- Several data gaps may be of importance for the results. For paper napkins, this is mainly chemicals for paper production and converting. For textile napkins, data gaps include material losses and sizing agents for weaving, transport packaging for transport from laundry service and use of detergent for laundry. More data gaps were identified for reusable napkins than for single-use napkins.

- The study is limited to four environmental impact categories: global warming, acidification, eutrophication and photochemical oxidant creation. One should be aware that other environmental impact categories may show different results regarding the relative environmental performance of the different products.

Based on these conclusions, the following recommendations are given to Duni for the continued environmental work with the three napkin types:

- Use the information on the most contributing life cycle stages as a basis for further environmental improvement of the environmental performance in the supply chain. The results depend for instance strongly on the amount of raw material that is used in the product (and the amounts of waste), as well as the type of electricity that is purchased. An active dialogue with suppliers is important, in order to cooperate in more eco-efficient raw materials and transport.

- Follow up new and potential improvements in the production processes and other parts of the life cycle by recalculating the environmental impact.

- Communicate to stakeholders on the different markets in order to work towards an effective after-use treatment of Duni products, such as incineration with energy recovery instead of landfilling of paper materials.

- Create certified environmental product declarations (EPDs) in an internationally-accepted system to communicate reliable environmental information to customers and stakeholders.

- Consider including additional environmental impact categories, such as toxicity and water use in future environmental life-cycle studies. This would, however, require extra additional data collection and verification.

- Educate sales personnel in strengths and weaknesses of the own and alternative products in order to give full information to customers.

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See Appendix E.

Appendix A Detailed goal and scope description

This appendix provides an in-depth description of the goal, scope and methodology used in the life cycle assessment (LCA) of single-use and reusable napkins for restaurant dinners. The intended audience is LCA experts and stakeholders interested in the methodology of this study. The life cycle inventory analysis is presented in Appendix B.

A.1 Goal

The goal of this study is to calculate the environmental impact (in terms of four impact categories used in the International EPD System[4]) of Duni single-use napkins and to compare their performance with that of reusable textile napkins of cotton and linen[5] based on literature and database data; see Table **2**. The napkins produced by Duni are based on actual products, while the two reusable napkins are estimated alternatives based on available product samples and data from literature. All napkins are modelled as white and without print.

The investigated markets are restaurants in Germany, Sweden and the United Kingdom. The product specifications and production are the same for the different markets. What differs is the difference in transport distance from converting to an average customer, the country-average electricity mix used during washing and the waste management scheme.

No manufacturer of reusable napkins has been involved in the study. As an attempt to avoid overestimations of the environmental impacts from these products, conservative assumptions have been made where possible and important assumptions have been checked in the sensitivity analysis.

Table 2: The table napkins investigated in this study, including information on the data source for the product specifications. All napkins are of "premium" type used at restaurants, why no 1- or 2-ply napkins used at cafeterias have been included.

	Type	Grammage (g/m^2)	Weight (g)	Size (cm x cm)	Data source
Duni tissue napkin	Single-use	45 (3 layers)	7.2	40x40	Duni (actual product)
Dunilin	Single-use	71	11.6	40.5x40.5	Duni (actual product)
Dunicel	Single-use	140	23.5	41x41	Duni (actual product)
Cotton napkin	Reusable	200	42.3	45x45 (46x46*)	Theoretical, based on samples & literature
Linen napkin	Reusable	220	46.6	45x45 (46x46*)	Theoretical, based on samples & literature

* To calculate the total weight of the napkin, it was assumed that the sides were folded by 0.5 cm per edge.

[4] Climate change, acidification, eutrophication and photochemical oxidant formation.

[5] Linen is here defined as the material made from the flax fibre.

The three Duni products are all "premium" products sold as possible replacements for textile napkins, e.g. the tissue napkins consists of three layers of tissue (EG, personal communication). The difference in size between paper napkins and reusable alternatives is consistent with actual conditions, where paper napkins are usually around 40x40 square centimetres while textile napkins are a bit larger (MF, personal communication). The results for the different napkins are still comparable as long as the systems still provide the same function for the end user (see Section A.2).

The study is an attributional LCA (as compared to a consequential LCA) that answers the question "what environmental impacts can be attributed to the use of a napkin?" Another type of question that could be asked is "what would be the environmental consequences of one additional use of a napkin (in a certain time perspective)?" It is important to note that the answer to these questions may be different from one another, and different conclusions may be drawn from the results. In the sensitivity analysis, it was tested if a consequential approach would change the conclusions (see Appendix D. For more information on the difference between attributional and consequential LCA, see for instance Curran et al. (2005) and Ekvall et al. (2005).

The results of this study were primarily intended for internal use to increase knowledge about the environmental impacts of paper napkins and the difference in performance between single-use products and reusable products. As Duni wished to make the study more robust for selected communication of the results to different stakeholders, a review by an external expert was initiated after the study was completed.

The modelling of the single-use napkins have been done in such a way as to simplify the process of creating certified environmental product declarations (EPDs) in the International EPD system (SEMCo, 2010).

A.2 Functional unit

In order to compare the different napkin systems, a corresponding functional unit must be used as a basis of comparison. In this study, the functional unit was chosen as "one use of a dinner napkin at an average restaurant" at three markets selected by Duni: Germany, Sweden and the United Kingdom.

All included single-use napkins are of "premium" type, i.e. the type of napkins used during restaurant dinners. Simpler 1- or 2-ply napkins normally used in cafeterias are not included. It was thus assumed that only the function of the napkin was not related to the absorption capacity of the napkins, and that any differences in material and size of the different products made no difference in providing this function for the final consumer.

A.3 System boundary

The system boundary has been chosen to cover all processes relevant for the comparison of single-use and reusable napkins. The focus has been on making the product systems comparable, and to cover all significant parts of the life cycle.

When dividing unit process into life cycle stages, care has been taken to use a similar system boundary as in the International EPD system (SEMCo, 2010). An exception to this is that the systems have been expanded at waste management to include the "avoided emissions" that occur due to the production of heat, power and material during incineration and recycling. The life cycle stage has been included anyway to make the single-use and reusable napkin systems comparable.

The study covers the entire life cycle of the products, from forestry or cultivation of cotton and flax to waste management of used products. The boundary between nature and the product life cycle is crossed when materials, such as crude oil, are extracted from the ground and when emissions occur to soil, air or water. In some cases, it has not been possible to trace some flows to the cradle or grave. These "cut-offs" are listed in Section B.7.2. Direct and indirect effects due to land use change have not been included due to uncertainty in data.

The study covers napkins used at three different markets, why process data have been chosen to reflect relevant production methods and products on these markets. Some processes such as cotton cultivation, take place outside Europe why data from the relevant geographical area have been used.

The choice of the geographical and technical system boundary for the electricity system is not trivial and requires careful consideration. In this study, the general practice in the International EPD System has been used (SEMCo, 2010). This means that if verifiable data on purchased electricity are available, this should be used, and if not, the country-average mix is used as an approximation. For a discussion on the possible impacts of this methodology choice, see the consistency check in Section D.4.

The study aims at describing the current conditions, why as recent data as possible has been used. For Duni products, paper production, converting and transports are based on data from 2009, as this was the latest data available when the study was performed. In the assessment of the greenhouse gas emissions and their potential global warming impact, a 100-year perspective has been used. The 100-year period is the most common perspective used in LCAs and in policy discussions concerning global warming, but one should note that it is somewhat arbitrarily chosen.

The life cycle of the products have been divided into the following life cycle stages (see Figure 12 and Figure 13):

- **Raw materials & energy**. For paper napkins, this includes forestry, transports to the pulp mill and the production of pulp. It also includes the production of raw materials such as glue and filler, chemicals, fuel and electricity for paper production and converting. For reusable napkins this includes cotton or flax cultivation, fibre processing and yarn processing.
- **Napkin**. For paper napkins, this includes transports of raw materials, chemicals and fuels to paper production, paper production (tissue paper or Airlaid paper) and converting. For reusable napkins this corresponds to the weaving process.
- **Distribution**. This is the transport from paper converting or weaving to an average restaurant at each market.
- **Laundry**. For reusable napkins, life cycle stage corresponds to the transportation of to and from an external laundry facility and the use of electricity and steam for washing the napkins. It also includes emissions from waste water treatment, and emissions of eutrophying substances to water. This life cycle stage is not relevant for paper napkins.
- **Waste management**. This includes emissions from transportation to waste management and emissions from incineration and landfill of the product and transport packaging. For materials intended for recycling, the transport waste to a sorting facility is included, but not the recycling processes as required by the International EPD System (SEMCo, 2008b).

- **Avoided emissions.** This includes alternative production of electricity, heat and materials as well as the recycling process for transport packaging intended for recycling.

As mentioned above, the life cycle stage "avoided emissions" is generally not included in the International EPD System. In order to use the results in an EPD, the life cycle stage avoided emissions should therefore be removed. In an EPD, the system boundary is generally set according to a "polluter pays" allocation principle. For incineration, the emissions caused by incinerating a good are allocated to the product producing the good, while no credit is given for the energy that is produced. (SEMCo, 2008b) The same is true for recycling: the product generating the material should take responsibility for the emissions caused by transportation to a sorting facility or recycling process, but the recycling process itself is allocated to the product system taking advantage of the material that is produced.

The system boundary and life cycle stages for single-use and reusable napkins are presented in the form of flow charts in Figure 12 and Figure 13.

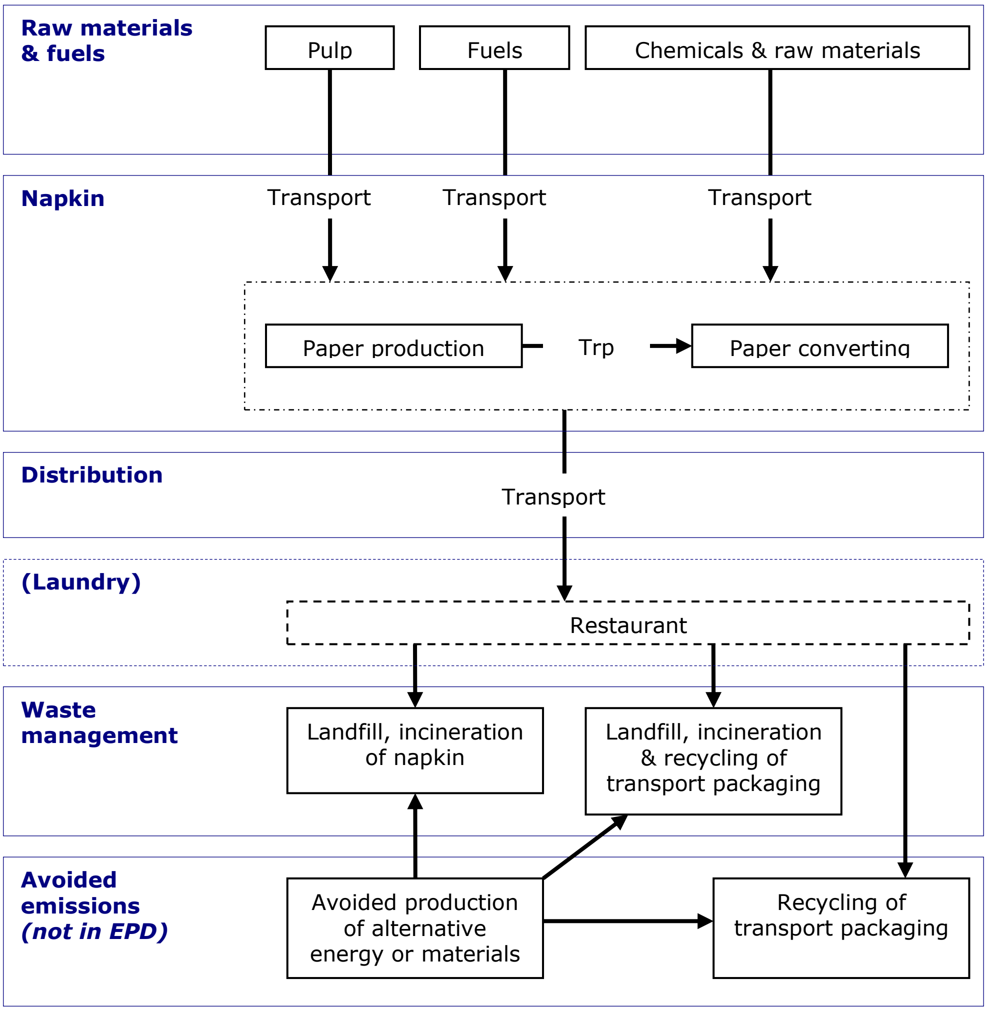

Figure 12 System boundary and life cycle stages for the single-use napkins – Duni tissue napkin, Dunilin and Dunicel.

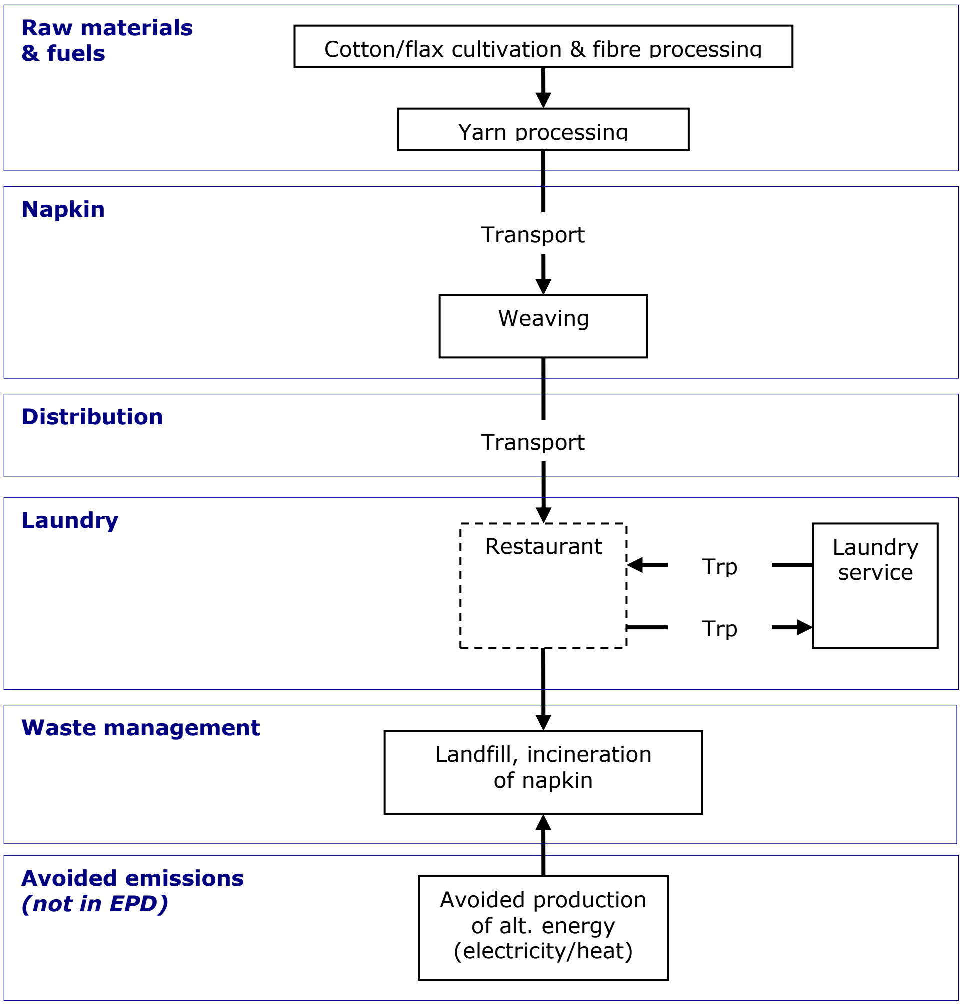

Figure 13 System boundary and life cycle stages for the reusable napkins – cotton napkin and linen napkin.

The largest difference between reusable and single-use napkins is the inclusion of the laundry service in the case of reusable napkins. The textile napkins were assumed to be washed 40 times during its life cycle, why only 1/40 of the material of a napkin was needed to be produced per use of napkin. After being used 40 times, the textile napkins were assumed to be discarded and collected together with the mixed municipal solid waste at each market.

A.4 Impact assessment categories

The potential environmental impacts of the systems are calculated in four separate categories: climate change, acidification, eutrophication and photochemical oxidant creation; see Table 3. These are the same environmental impact categories that are included in the International EPD System, with the exception of stratospheric ozone depletion potential (SEMCo, 2008b).

They were chosen as they comprise a quite diverse set of impact categories, are well-established in terms of availability in LCA literature and databases, and because of their inclusion in the International EPD System. One should, however, be aware that other impact categories may be relevant for a full environmental assessment of these products. Characterisation factors referenced in SEMCo (2008b) were used. The results are presented separately in absolute values as well as relative to the Duni tissue napkin.

Table 3: Environmental impact assessment categories used in this study.

Impact category	Characterisation model	Unit[6]	Primary source (SEMCo, 2008b)
Climate change	GWP, 100 years	g CO_2 equivalents	IPPC (2001)
Acidification	AP	mg SO_2 equivalents	CML (1999), Huijbregts (1999)
Eutrophication	EP	mg PO_4^{3-} equivalents	CML (1999), Heijungs et al. (1992)
Photochemical ozone formation	POCP	mg C_2H_4 equivalents	CML (1999), Jenkin & Hayman (1999), Derwent et al. (1998)

In addition to the environmental impact categories listed above, primary energy use is also calculated and presented. As no specific data were available on the production of reusable napkins, the data quality for land use, human toxicity, ecotoxicity and impact of water use were considered low. These impact categories have thus not been possible to include in this study.

The aggregation of impact categories into a single score – "weighting" – has not been performed as this frequently requires a value judgement of the relative importance of different impact categories. This assessment is left up to the reader.

A.5 Comparisons between systems

The product specification, system boundary, functional unit, etc., have been chosen in order for the systems to be comparable for use at restaurants in each of the three countries and to comply with the general requirements of the International EPD System. Like all sets of LCA methodologies, this has its limitations as a reference for the system boundary, included impact categories and other methodological choices. It was chosen anyway for its transparency, international accessibility and applicability if Duni would like to proceed with EPDs of their products in the future.

In order to make the systems comparable, the system boundary has also been expanded at waste management to include avoided emissions at each market.

The following issues have been identified as potentially problematic for a fair comparison of the systems:

- There are data gaps in the life cycle inventory analysis (see Section 0)
- The paper napkins are based on the actual supply chains of Duni, while the reusable napkins are based on estimated alternative products. The area for which this might have the largest impact is the source of electricity. Assumptions such as the size and number of washes for reusable napkins are checked in the sensitivity analysis (see Appendix D).

[6] Abbreviations: CO_2 = carbon dioxide; SO_2 = sulphur dioxide; PO_4^{3-} = phosphate; C_2H_4 = ethene.

The study has been performed in accordance with the international standard of life cycle assessment, ISO 14044. (ISO, 2006). In its current version, the ISO standard requires a review by a panel of interested parties (three persons) for studies that include "comparative assertions" to the public. As this report has been reviewed by only one independent external reviewer, the ISO standard is no longer followed if used to support such "comparative assertions" to the public.

A.6 Interpretation methods

In order to analyse the robustness of the results and conclusions, several interpretation methods have been used in Appendix D.

A.6.1 Data uncertainty check

The data uncertainty check is performed to identify inconsistencies between the choice of data sources for the LCI.

A.6.2 Sensitivity analysis

The sensitivity analysis should analyse key assumptions to answer the question: *are the results still valid if other assumptions are made*? The following parameters were analysed in the sensitivity analysis:

- **Number of wash cycles for reusable napkins**. In the base case, it was assumed that the textile napkins are washed 40 times before being discarded. In this sensitivity analysis, the number of wash cycles in the life cycle of a textile napkin is varied to 20, 40 and 60 cycles for use on the German market.
- **Size of reusable napkin**. In the base case, the single-use napkins were assumed to be about 40x40 square centimetres, while reusable napkins were assumed to be 45x45 square centimetres. This is based on actual conditions, where textile napkins often are a bit larger than paper napkins. In this sensitivity analysis, the size of the cotton and linen napkin are assumed to be smaller: 35x35, 40x40 and 45x45 square centimetres.
- **Energy use for weaving.** In the base case, an electricity use of 10.6 MJ/kg fabric was used for weaving. Here, this was compared to a case where only 5.4 MJ/kg fabric was required for the cotton napkin used on the German market.
- **Low-carbon electricity at laundry service.** In the base case, a country-average supply mix of electricity was used at laundry service. In this sensitivity analysis electricity produced from renewable energy sources was used and compared to the base case.
- **Methane emissions at landfill.** In the base case, it was assumed that 227 grams of methane is formed per kg of cellulose deposited at landfill. Here, it was assumed that 200 g/kg or 250 g/kg is formed.
- **Marginal electricity.** In the base case, a country-average supply mix of electricity was generally used throughout the product life cycle. In this sensitivity analysis, electricity produced from hard coal (short-term marginal electricity) was used instead, where possible, to simulate a simplified consequential LCA approach; see Section A.1.
- **Best case scenario for reusable napkins.** In the other sensitivity analyses, only one parameter has been checked at a time. Here, the number of wash cycles for reusable

napkin, the napkin size, the energy use for weaving and the type of electricity used at laundry service are varied all at once to form a "best case" scenario for the two reusable napkin systems.

A.6.3 Completeness check

The completeness check is performed in order to answer the question: *do the identified data gaps have a potentially significant impact on the results and the conclusions*? The data gaps are analysed one by one by assuming an environmental load or process associated with it. The total result in terms of global warming potential (GWP) is then recalculated and conclusions are draw regarding the significance of the data gap.

A.6.4 Consistency check

The consistency check is performed in order to answer the question: *is the modelling and methodology appropriate for the goal and scope of this study*? This analysis is mainly qualitative, discussing the different issues that were raised in Section A.5.

A.6.5 Dominance analysis

The dominance analysis should analyse the results to answer the question: *what life cycle stage(s) is (are) the most dominant contributor to the total results*? Each product system and environmental impact category is analysed and discussed separately. An additional analysis is made on the life cycle stage "raw material and energy" for Dunicel in order to investigate which raw materials contribute most to the total impact.

Appendix B Life cycle inventory analysis

This section describes the data collection, modelling and results of the life cycle inventory (LCI) analysis. Data was collected from various sources for the different products. The focus was to gather site-specific data for paper production and paper converting as these processes are the one over which Duni has the most control. Data from literature and databases were used for alternative products, and for general processes such as fuel and electricity production.

Modelling and calculation of results were done in the LCA software GaBi 4 Professional.

B.1 Product specifications and transport packaging

Duni tissue napkin, Dunilin and Dunicel and are based on existing products, where product specifications were provided by Duni (HJS, personal communication). The reusable napkins of cotton and linen are estimated alternative products, based on samples and literature data.

Duni tissue napkin and Dunilin are made out of paper (tissue paper or Airlaid paper), while Dunicel contains tissue paper and a large part of glue and filler. The production of the filler was approximated with limestone flour and the glue was assumed to consist of about 50% ethylene vinyl polymer and 50% water.

Transport packaging for the different napkins are listed in Table **4**. Data on transport packaging for single-use napkins were provided by Duni (HJS, personal communication). No information was available on the amount of transport packaging for reusable napkins of cotton and linen, why it was assumed that they had no transport packaging. This is very likely an underestimate of actual conditions.

For production of transport packaging, data from PE International (2006) were used.

Table 4: Transport packaging for the studied napkins. No information was available on the amount of transport packaging for reusable napkins of cotton and linen, why it was assumed that they had no transport packaging.

	Cardboard (g/napkin)	Corrugated cardboard (g/napkin)	Polypropylene film (g/napkin)
Duni tissue napkin	0.12	0.63	0.060
Dunilin	0.00	0.67	0.15
Dunicel	0.00	0.91	0.15
Cotton napkin	–	–	–
Linen napkin	–	–	–

B.2 Paper napkins

This section provides information on the LCI of the Duni paper napkins. For a summary of data gaps, see Section B.7.2.

B.2.1 Pulp production

Pulp for tissue paper or Airlaid paper is purchased from various suppliers. Requests for data were sent out to the largest suppliers and data was received from Södra and SCA Graphic Sundsvall, while the supplier for pulp for Airlaid paper did not respond to the request (ET, personal communication; CL, personal communication). While investigating the completeness and quality of the data, it was concluded that some of the impact categories such as eutrophication did not appear to be represented in a fair way between the different data sets. Database data from PE International (2006)[7] was therefore used for all napkins in order for the comparison to be fair.

B.2.2 Paper production

The production of tissue paper and Airlaid paper takes place in Skåpafors and Dals-Långed in Sweden for which site-specific data for 2009 were provided by Rexcell (PL & MJ, personal communication). The data covered raw materials, chemicals (used for cleaning, waste water treatment, etc.), transport packaging, fuel and electricity use, water, emissions to air and emissions to water. The data also included actual transportation distances and transportation modes for pulp (truck or train), other raw materials and waste for 2009.

Most parameters, such as chemicals, energy use, etc., were possible to allocate to each product due to the high resolution of data in the local environmental and quality management system. Data on waste was provided in a format that was already allocated on a per-machine basis. Most raw materials, fuels and chemicals could be traced to the cradle by using database data. Exceptions are listed in Section B.7.2.

The electricity mix used for paper production was the Nordic production mix supplier Vattenfall in 2008 with process data from EPDs developed by Vattenfall (Vattenfall, 2005; Vattenfall, 2009).

B.2.3 Converting

Converting of tissue and Airlaid paper into napkins takes place in Bramsche (Germany) for all Duni products in this study. Data for the converting site was provided by Duni and included information about raw materials, transports, energy carriers, power and water use, co-products, wastes, etc. (HJS, personal communication). Specific data on transports were provided for the raw materials, transport packaging and the most important chemicals.

Information on electricity and natural gas use during production was allocated to each product by Duni. Raw materials, such as tissue paper and Airlaid paper, were allocated with mass allocation to the napkins and other products that utilised the specific raw material. Aggregated numbers for the site, such as water use, liquefied petroleum gas for trucks, natural gas for heating and emissions to water were allocated to all products based on mass. The number on water use includes the water

[7] Data set: SE: Sulphate pulp unbleached

used for offices, toilets, etc., why this should be an overestimate of the water need for the converting process.

Information was provided on the share of purchased electricity that comes from different sources. The largest share comes from fossil energy, but the mix also contains a large share of nuclear power and a part of renewable energy (HJS, personal communication). This closely resembles the German supply mix, why this mix was used as an approximation (see Section B.4).

B.3 Textile napkins

This section provides information on the LCI of textile napkins. For a summary of data gaps, see Section B.7.2.

B.3.1 Cotton production

Cotton was assumed to be cultivated in China and the United States as these countries together accounted for about 43% of the global production in 2004–2005 (Kooistra & Termorshuizen, 2006). Process data from the Ecoinvent database were used (Nemecek and Kägi, 2007)[8].

During cultivation, fertilizers and pesticides are used in order to increase yields. Examples of fertilizers used are ammonia, urea, diammonium phosphate and potassium chloride. Besides the main product (cotton fibre), the cotton plant also yields cotton seeds. Approximately 1144 kg cotton seed is harvested when 775 kg cotton fibre is harvested (Nemecek and Kägi, 2007). The cotton seed make up approximately 13% of the economic value of the total harvest, thereby allowing for economic allocation.

After cultivation, fibre processing and yarn processing takes place. Data for these processes are included in the aggregated data set but there is no detailed information about them available. (Nemecek and Kägi, 2007)

B.3.2 Flax production

Cultivation

Cultivation of flax is to a large extent performed in Western Europe due to its climate with temperatures generally below 30 °C (Turunen and van der Werf, 2006). The data used in this study are based on production practices in France, Belgium and the Netherlands, but with a French electricity mix. This electricity mix should be a conservative estimate for the environmental impact categories included in this study.

During cultivation, fertilizers and pesticides are used in order to increase yields. Common fertilizers are ammonium nitrate, triple superphosphate and potassium chloride. The pesticides used are mainly herbicides to limit the growth of weeds and fungicides used to treat the sowing seeds. Both sowing and harvesting is performed mechanically. Besides the main product (flax stems) the fibre flax crop also produces seeds that are firstly used for sowing crop. The surplus seeds can be sold for other uses, for example oil extraction and animal feed. According to Turunen and van der Werf,

[8] Data set: GLO: yarn, cotton, at plant, with an updated US electricity mix.

(2006), the price of both stem and seeds are equal, thereby allowing for mass allocation to be used as an approximation to economic allocation.

Fibre processing

The fibre processing consists of several processes that prepare the flax fibres for the yarn processing. First, the flax is retted in order to separate the outer fibre bundles from the non-fibrous bark and woody core (Dissanayake et al, 2008). There are different retting methods available. Dew-retting is a common method used due to its low labour intensiveness (Akin, 2003). Dew-retting generally takes between 3 weeks and 3 months depending on the weather. During the retting, the fibres need to be turned at least once to allow for even retting. In the data used here, turning was assumed to take place two times during the retting procedure. After retting, the flax fibres are baled and collected.

The last step of the fibre processing is scutching, which is a mechanical process where the fibres are separated from the bark and woody core. During the scutching process, shives and short tow fibres are also separated from the long fibres which later will be used for the yarn production. The products produces in the scotching process are scotched long fibre, scotching tow and shives, which all can be sold as separate products.

Yarn processing

The major processes during the yarn production are hackling, bleaching, spinning and yarn winding (Turunen and van der Werf, 2006). During the hackling, the fibre bundles are further separated to allow for spinning later on. The products from the hackling are sliver and hackling tow. The next step is bleaching. It is performed in order to whiten the yarn as well as to remove residual pectins and hemicelluloses. After these preparatory steps, the fibres are spun and the resulting yarn is then winded onto cones.

B.3.3 Weaving of cotton and linen

During the weaving, the yarn is turned into a fabric by interlacing the yarns at different angles. To avoid breaking of the warp yarn during weaving, the yarn is pre-treated with sizing agents consisting of natural or modified starches (Kallila and Talvenmaa, 2000). These sizing agents are later removed when the fabric is washed and coloured during the finishing processes.

Regarding the electricity used during the weaving process, there are some differences in published data. Kallila and Talvenmaa (2000) state that approximately 5.4 MJ/kg fabrics is needed while Greener chemistry (2004:6) states that 10.6 MJ/kg fabric is needed. A third article (Turunen and van der Werf, 2006), states that approximately 15–47 MJ/kg fabric is needed. In this study, 10.6 MJ/kg fabrics has been used to attempt to avoid overestimating the impact from weaving.

Weaving was assumed to take place in Europe, using an average EU-25 electricity mix. Material losses were assumed to be small.

B.3.4 Laundry service

The dirty napkins were assumed to be transported 100 km by a small truck (max 5 tonnes payload) to a laundry service facility. A napkin was assumed to be used and sent to a laundry service facility an average of 40 times during its life time before being discarded.

It was assumed that the facility used 0.3 kWh of electricity, 2 kWh of steam and 12 litres of water per delivered kilogram of laundry. It was assumed that the steam was produced from natural gas, as natural gas and oil are the most common fuels for this purpose (SEMCo, 2008a). This energy use corresponds to the criteria for a Swan-labelled laundry facility (Nordic Ecolabelling, 2009), and is thus likely a low estimate for an average site. For comparison, the most recent number on average energy use in Swedish laundry facilities that was found is from 1999. In that year, 0.47 kWh of electricity, 2.22 kWh of steam and 19 litres of water were used per kilogram of laundry (SEMCo, 2008a).

The output water from laundry was assumed to be handled in a medium-sized municipal waste water treatment plant. The three markets in this study (Germany, Sweden and the UK) all have high connectivity to waste water treatment and relatively high rates of chemical and/or biological treatment of sewage (Doka, 2007). Process data from Doka (2007) were used.

No information was available regarding the amounts of bleach, starch, softener and detergent that are used at an average laundry site, why the production of these chemicals constitutes a data gap.

B.4 Electricity

As described in Section A.3 the general practice of the International EPD System has been used to set the geographical and technical boundary of electricity production (SEMCo, 2008b).

Specific electricity use has been used in the paper production in Skåpafors based on the production mix of the electricity supplier Vattenfall in 2008 (Vattenfall, 2009). For other parts of the life cycles, the country-average power supply mix for 2006 from IEA (2008a; 2008b) was used for electricity. This practice means the following assumptions for some of the most important countries in this study[9]:

- **China**: mainly power from coal (79% of production), but also some hydro power (17%).
- **Finland**: nuclear power is the main energy type (30% of production), but it is not dominant in the electricity mix as coal (19% of production), natural gas (15% of production), biomass (13% of production), hydro power (22% of production) and imports from Russia all play an important part.
- **France**: mainly nuclear power (76% of production), but also some hydro power (12% of production) and a power from fossil resources (10% of production).
- **Germany**: more than half of the electricity supply from fossil resources (coal and natural gas: 61% of production), but also a large share of nuclear power (23% of production) and a larger share of wind power (6%) than in other countries.
- **Sweden**: mainly nuclear power (43% of production) and hydro power (46% of production), but some imports of hydro power and power from fossil resources from neighbouring countries.
- **United Kingdom**: mainly coal (33% of production), natural gas (45% of production) and nuclear power (14% of production). Some imports of mainly nuclear power from neighbouring countries.

[9] The figures in this list are based on public electricity production data from 2008 (IEA, 2011).

- **United States**: mainly coal (49% of production), but also important shares of natural gas (21% of production) and nuclear power (19% of production).

In addition to this, an average EU-25 electricity mix[10] from PE International (2006) was used when the European country in which a process takes place was unknown. The most important example of this is weaving of cotton and linen napkins.

B.5 Transports

For all transports by truck, emissions data from PE International (2006) was used with known transport distances and types. Not all transport data for the transport of raw materials, etc., were available. For these unknown transports, a default truck with a maximum payload of 22 tonnes, 70% cargo capacity utilization and a transport distance of 500 km was used[11].

In 2005, about 70% of the diesel in EU-27 had a sulphur content of less than 10 ppm (European Energy Agency, 2009). The sulphur content of all truck fuels was thus adjusted to 10 ppm to reflect current European levels.

Distribution of Duni napkins is done by truck from the converting site to different distribution centres before being delivered to a customer. Data on transport from the converting site to the distribution centre was provided by Duni (EG, personal communication).

For transports from the distribution centre to a customer in Germany, data for 2009 was provided from the German logistics company on the total emissions of CO_2 and NO_x (EG, personal communication). Based on this data, the average emissions of distributing napkins to the German market were calculated.

For transports from the distribution centre to a customer in Sweden, data for 2009 was provided by one of the logistics companies (EG, personal communication). These data were assumed to be representative for the average transport distance (400 km) and the cargo capacity utilization rate in Sweden.

For transports from the distribution centre to a customer in the United Kingdom, the same distribution as in Germany was assumed.

Distribution of textile napkins was assumed to take place by truck (1000 km) for textile napkins to the three markets.

B.6 Waste management and avoided emissions

No specific data was available on the average fate of a napkin after use on the three markets. To calculate the emissions from waste management, scenarios based on statistics country-specific statistics had to be used.

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[10] Data set: EU-25: Power grid mix

[11] Data set: GLO: Truck 28-32 t total cap. / 22 t payload / Euro 3

For emissions from incineration of different incineration, landfill and recycling processes, data was mainly taken from PE International (2006) with the exception of recycling of plastics that were taken from Umberto et al (2003) and landfill of organic material, which is described in detail in Section B.7.1

B.7 Waste management scenarios

The waste management scenarios for paper, cotton and linen napkins are shown in Table 5. It was assumed that all napkins were collected together with the mixed municipal solid waste. The ratio between landfill and incineration at each market were based on Eurostat (2009b), where recycling and composting were assumed to be zero.

Table 5: Waste management scenario for municipal solid waste (paper, cotton and linen napkins) at the three markets. The ratio between landfill and incineration is based on Eurostat (2009b).

	Material recycling	Landfill	Incineration	Compost
Germany	–	3%	97%	–
Sweden	–	8%	92%	–
United Kingdom	–	86%	14%	–

The waste management scenario for plastic packaging is shown in Table 6. Data on recycling and separate collection of plastic packaging are based on Eurostat (2009a). The share of plastic packaging put on the market but not accounted for was assumed to be treated as municipal solid waste based on Eurostat (2009b). The share of plastic packaging that is incinerated is thus a combination of the plastic packaging that was separately collected and the plastic that was incinerated together with the municipal solid waste.

Table 6: Waste management scenario for plastic packaging on the three markets based on Eurostat (2009a; 2009b). The share of plastics that is incinerated is a combination of the plastic packaging that was collected separately and the plastics collected as mixed municipal solid waste. Numbers may not add up due to rounding.

	Material recycling	Landfill	Incineration	Compost
Germany	43%	0%	57% (53%+5%)	–
Sweden	42%	2%	56% (37%+19%)	–
United Kingdom	23%	58%	19% (9%+10%)	–

The waste management scenario for corrugated cardboard is shown in Table **7**. Data on recycling and separate collection are based on statistics for paper and cardboard in Eurostat (2009a). The remaining share was assumed to be treated as municipal solid waste based on Eurostat (2009b).

Table 7: Waste management scenario for packaging of cardboard and corrugated cardboard on the three markets based on Eurostat (2009a; 2009b). The share of material that is incinerated is a combination of the packaging that was collected separately and the packaging that was collected as mixed municipal solid waste.

	Material recycling	Landfill	Incineration	Compost
Germany	80%	0%	20% (18%+2%)	–
Sweden	74%	1%	15% (0%+15%)	–
United Kingdom	79%	11%	10% (8%+2%)	–

B.7.1 Methane emissions at landfill

When organic material such as paper, cotton of linen is deposited at landfill, methane is formed and emitted to the atmosphere or collected/incinerated to replace other forms of heating. It was assumed that 227 grams of methane was formed during 100 year per kilogram of cellulose deposited at landfill (Sundqvist, 1999). The amount of formed methane that is collected during 100 years is difficult to estimate, why 50% (114 g) was assumed for Germany, Sweden and the United Kingdom.

The methane that is not collected is emitted, but some methane is oxidized before entering the atmosphere (Sundqvist, 1999). It was thus assumed that 102 grams of methane is emitted to the atmosphere per kilogram of cellulose deposited at landfill.

For tissue paper and Airlaid paper, a dry weight of 90% and a cellulose content of 50% were assumed. For reusable napkins, a cellulose content of 91.5% of dry weight and 77% of dry weight were assumed for linen and cotton based on Reddy and Yang (2005). The dry weight was assumed to be 90% of the total weight of the napkins.

B.7.2 Avoided emissions at waste management

The energy carriers and recycled materials that are produced at waste management are assumed to replace alternative production by another system. The electricity generated at incineration is assumed to replace average electricity at each market. Heat produced from incineration and from combustion of the landfill gas that is collected is assumed to replace heat from natural gas in the United Kingdom and Germany, and heat from biomass in Sweden.

The following materials are assumed to be replaced due to recycling:

- **Polypropylene** (plastic foil): virgin polypropylene granulates
- **Cardboard**: linerboard from virgin raw materials
- **Corrugated cardboard**: linerboard from virgin raw materials

B.8 Known data gaps

The following data gaps are known to exist in the LCI. This lack of data is analysed in Section D.2.7.

Product specifications and transport packaging:

- Data on transport packaging for napkins of cotton and linen is missing. No transport packaging was assumed for the reusable napkins.

Pulp production:

- Site-specific data for some pulp types missing or incomplete to account for all environmental impact categories. Database data was therefore used for production of pulp of all type included in this study.

Paper production and converting:

- Chemicals for tissue paper and Airlaid paper production: about 0.2 g/Duni tissue napkin, 0.03 g/Dunilin napkin and 0.3 g/Dunicel napkin.
- Chemicals for converting: about 0.002 g/Duni tissue napkin, 0.003 g/Dunilin napkin and 0.4 g/Dunicel napkin.

Cotton and flax cultivation and processing of fibre and yarn:

- *No known data gaps.*

Weaving of cotton and linen:

- Material losses during weaving.
- Production of sizing agents (polyvinyl alcohol).
- Emissions to water (chemical oxygen demand, COD, from sizing agents).

Laundry service:

- Production of bleach, starch, softener and detergent used at an industrial laundry site.
- Transport packaging used for return transport of clean napkins to restaurant.

Waste management:

- *No known data gaps.*

B.9 Allocation

For the production of cotton, allocation between cotton seed and cotton fibres were avoided in Nemecek & Kägi (2007) for some parameters such as carbon dioxide uptake. Other inputs were divided over the two products based on economic allocation (Nemecek & Kägi, 2007). Using this method increases the impact allocated to the cotton fibres compared to using a mass allocation.

For the flax cultivation and scotching processes, the allocation between the main product and the co-products were performed on an economic basis. For flax cultivation, no absolute prices were known. As the relative price of flax stems and seeds are about equal according to Turunen and van der Werf, (2006), an allocation based on mass was used as an approximation for economic allocation.

For paper production, the allocation of inputs and outputs between tissue paper and Airlaid paper could easily be done due to the detail of provided data for inputs such as raw materials, chemicals and fuels.

For converting, mass allocation was used for most parameters such as emissions to water, waste and chemicals to allocate between the different products converted at the same site. For raw material inputs and chemicals that could be traced to a set of products, such as glue and filler, the materials were allocated to the relevant products based on physical relationships and approximated material losses during converting. Data on electricity and natural gas use were provided per product type from the site.

For the laundry service, the electricity and water use were calculated per kilogramme of washed laundry as this was the only reasonable way to model the collected data. It is unknown whether laundry facilities charge different rates (per kg of laundry) for different types of industries and compositions of the received laundry.

To avoid allocation of the waste management processes, such as recycling of transport packaging and incineration with energy recovery, a system expansion was performed to account for avoided emission related to the use of energy and material in other product life cycles (Section B.7.2). In this way, the environmental impact of waste management and the potential environmental benefit for producing material, heat and electricity used in other product systems could be presented separately.

B.10 Selected results from the life cycle inventory analysis

Table **8** presents the results for primary energy demand (renewable and non-renewable) for napkins on each of the three markets.

Table 8: Total primary energy demand (as gross calorific value) for the five napkin systems on the German, Swedish and British markets (unit: MJ/use of napkin). Numbers have been rounded to two valid digits.

Napkin	Germany	Sweden	United Kingdom
Duni tissue napkin	0.085	0.16	0.15
Dunilin	0.27	0.39	0.38
Dunicel	0.59	0.77	0.78
Cotton napkin	0.82	0.76	0.81
Linen napkin	0.93	0.87	0.92

Appendix C Additional characterisation results

This appendix provides additional characterisation results for acidification potential and photochemical oxidant creation potential for products on the three markets.

C.1 Acidification and photochemical oxidant creation, Germany

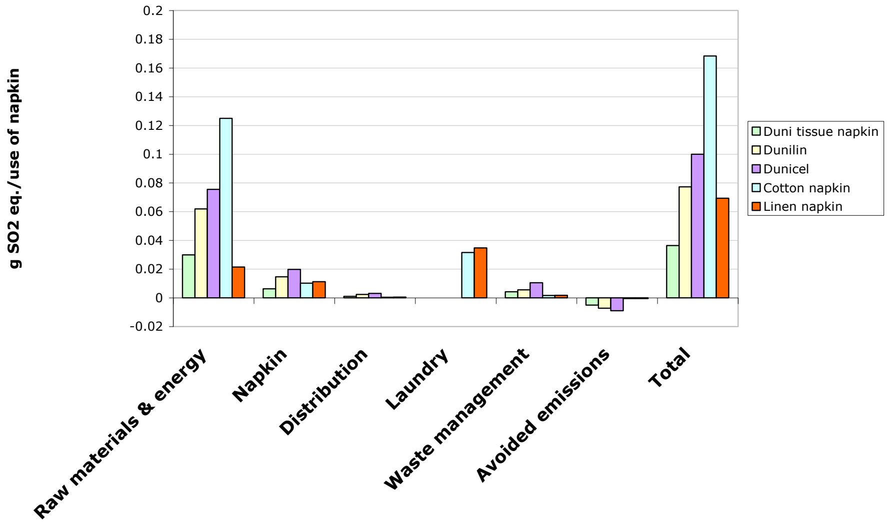

Figure 14 Acidification potential for the five napkin systems on the German market (unit: g SO_2e/use of napkin).

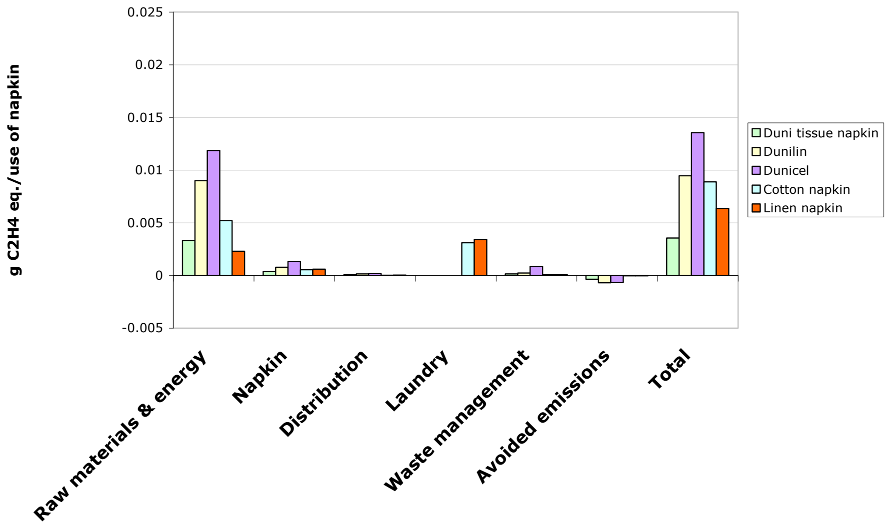

Figure 15 Photochemical oxidant creation potential for the five napkin systems on the German market (unit: g C2H4e/use of napkin).

C.2 Acidification and photochemical oxidant creation, Sweden

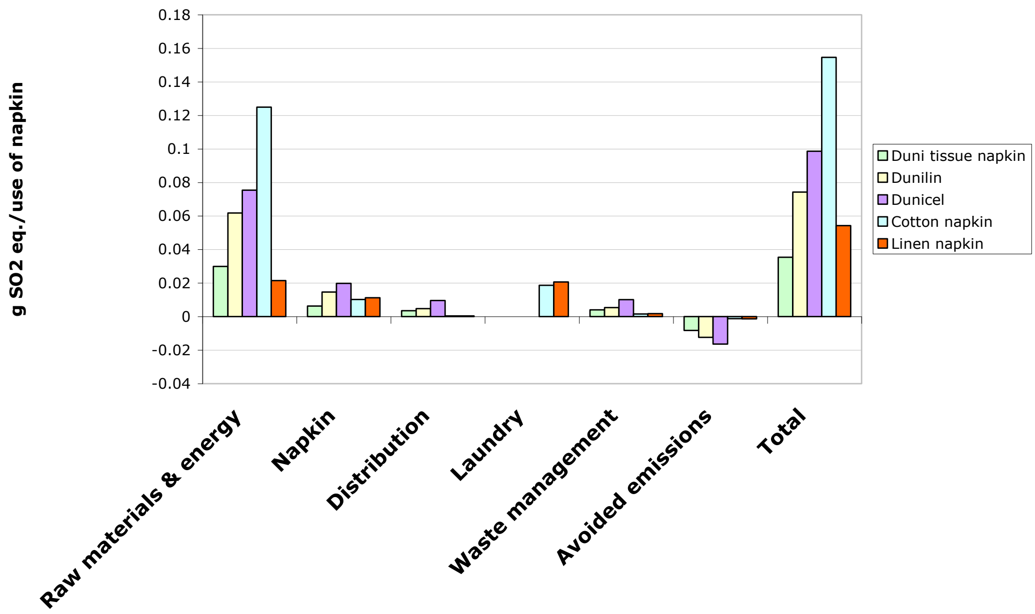

Figure 16 Acidification potential for the five napkin systems on the Swedish market (unit: g SO2e/use of napkin).

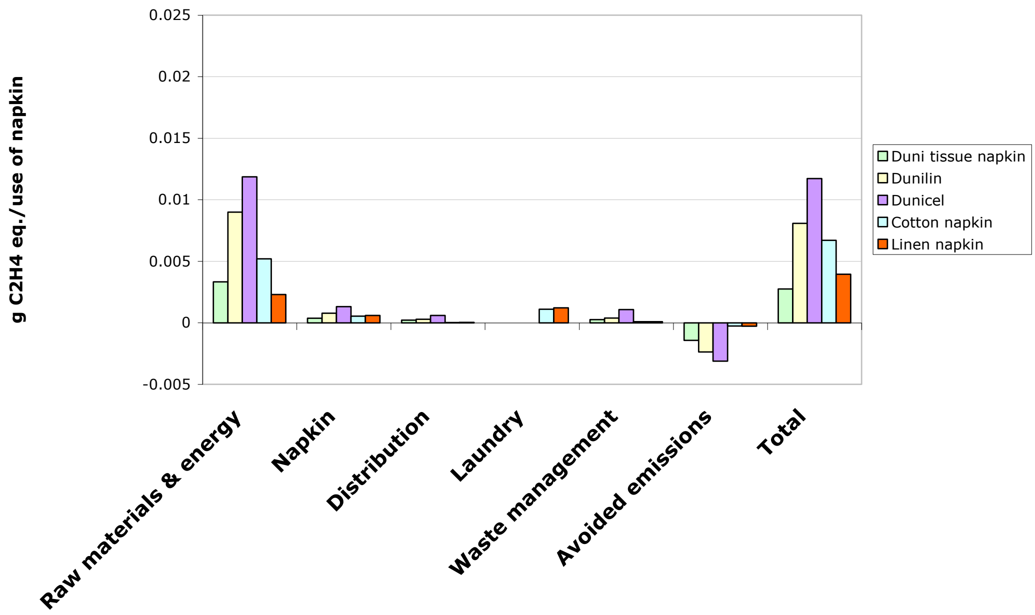

Figure 17 Photochemical oxidant creation potential for the five napkin systems on the Swedish market (unit: g C2H4e/use of napkin).

C.3 Acidification and photochemical oxidant creation, United Kingdom

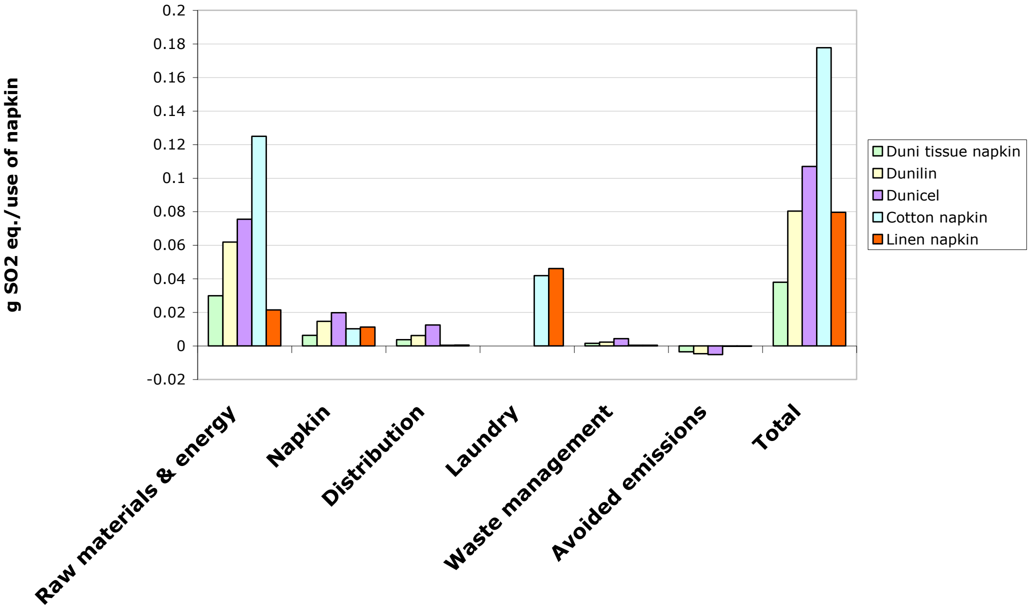

Figure 18 Acidification potential for the five napkin systems on the British market (unit: g SO2e/use of napkin).

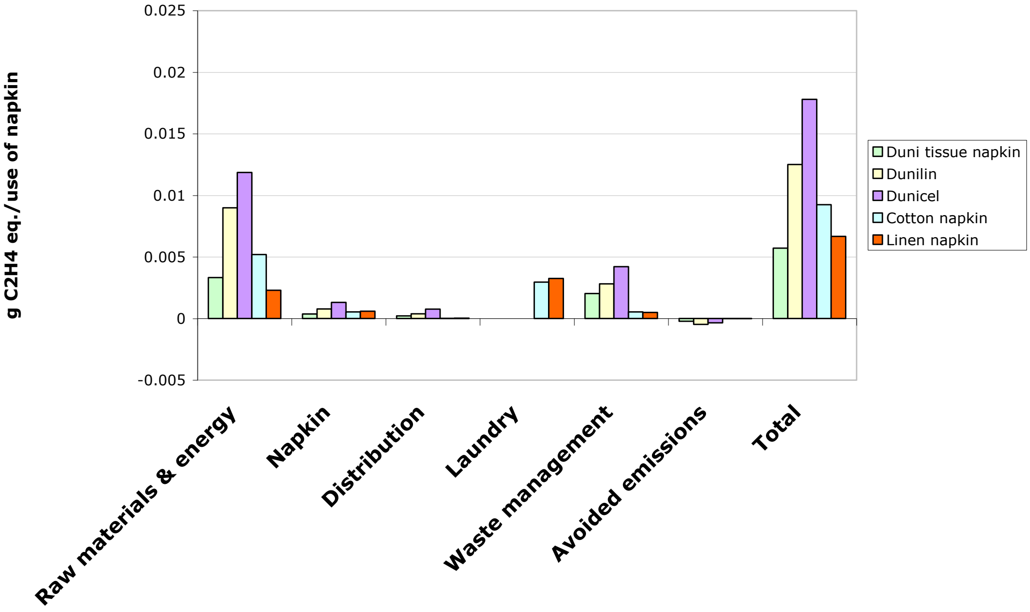

Figure 19 Photochemical oxidant creation potential for the five napkin systems on the British market (unit: g C2H4e/use of napkin).

Appendix D Detailed interpretation of results

This appendix provides the interpretation of the results in the form of a data uncertainty check, sensitivity analysis, dominance analysis, completeness check and consistency check.

D.1 Data uncertainty check

The uncertainty in data may increase when inconsistent data sources are used for the LCI. In this study, as in almost all LCAs, a combination of specific and database data has been used. Table **9** compares the data sets used for different parts of the LCI for different products to draw conclusions regarding the comparability of the uncertainties.

Table 9: Comparison of data uncertainty between different product systems.

Life cycle stage	Duni products	Cotton napkin	Linen napkin	Conclusion
Main raw materials	GaBi Professional DB (pulp, filler)	Ecoinvent (cotton)	Literature data (flax)	**Different data sources**
Energy generation	IEA statistics and Ecoinvent	IEA statistics and Ecoinvent	IEA statistics and Ecoinvent	Consistent choice of data source
Napkin (production)	Site-specific Duni data (tissue/paper production and converting)	Literature data (weaving)	Literature data (weaving)	**Inconsistent choice of data (specific vs. average product)**
Distribution	GaBi Professional DB (truck)	GaBi Professional DB (truck)	GaBi Professional DB (truck)	Consistent choice of data source
Laundry	N/A	Literature data (laundry facility)	Literature data (laundry facility)	Consistent choice of data source
Waste management	GaBi Professional DB and others (incineration, landfill…)	GaBi Professional DB and others (incineration, landfill…)	GaBi Professional DB and others (incineration, landfill…)	**Some differences in data sources**
Avoided emissions	IEA statistics, Ecoinvent and GaBi Professional DB	IEA statistics, Ecoinvent and GaBi Professional DB	IEA statistics, Ecoinvent and GaBi Professional DB	Consistent choice of data source

The table shows that there are some inconsistencies in the choice of data between different products. Some of these are expected, as is the case with inconsistent data source for the napkin production. The Duni napkins are based on data from a specific plant, while the manufacturing processes of the reusable napkins are averages based on literature and databases.

For raw material production, different data sources have been used for different raw materials. This choice was made to comply with the geographical, technological and time-related system boundary as specified in Section A.3. The same is true for waste management processes, where the most relevant data sets have been chosen.

To check if the results and conclusions might change as a result of these differences in data uncertainty, sensitivity analyses have been added for energy use for weaving and methane emissions from landfill of organic material.

D.2 Sensitivity analysis

In the sensitivity analysis, some key assumptions were varied and the results analysed in order to see if a change in the assumptions could result in different results and conclusions of the study.

D.2.1 Number of wash cycles for reusable napkins

In this sensitivity analysis, the number of wash cycles that a reusable napkin goes through during its life time is analysed. In the base case, it was assumed that the textile napkins are used and washed 40 times before being discarded. In this sensitivity analysis, the number of wash cycles in the life cycle of a textile napkin is varied to 20, 40 and 60 cycles for the cotton napkin on the German market, as this was judged to be a reasonable range of variation. The base case Duni tissue napkin is included in for comparison. The results for all impact categories relative to the Duni tissue napkin are presented in Figure 20.

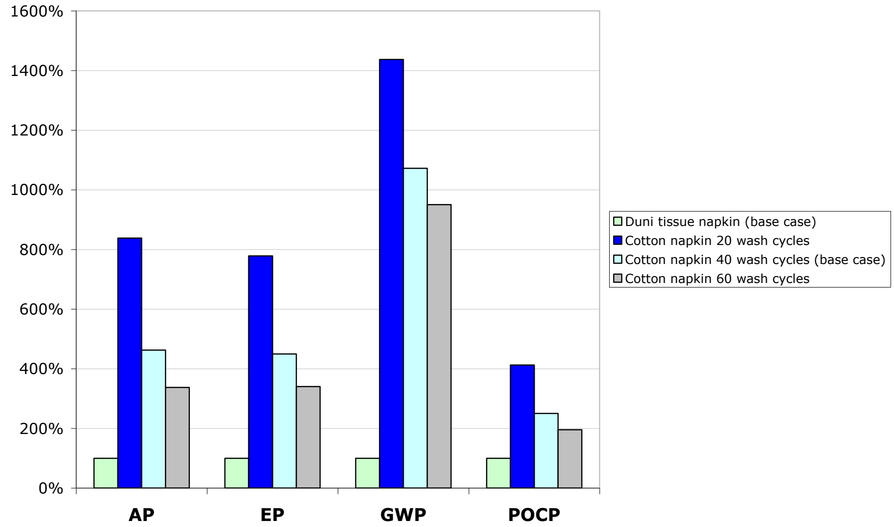

Figure 20 Sensitivity analysis of the importance of the assumed number of wash cycles for the reusable napkins on the German market. The included number of cycles are 20, 40 (base case) and 60. The results of the base case Duni tissue napkin has been set to 1 (100%) in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the results are rather sensitive to assumed number of wash cycles for the reusable napkins. The different impact categories have different sensitivities to this change, but common for all of them is that a reduction of the number of wash cycles by 20 has a larger impact on the results than an increase by the same number. This occurs because the life cycle stages raw materials & energy, napkin, distribution and waste management are all related to the inverse of the number of cycles (1/20, 1/40 and 1/60 respectively).

If the cotton napkin was washed and reused an infinite number of times (extreme case), the results would converge towards the environmental impacts of the laundry service, i.e. about 90% (AP), 120% (EP), 710% (GWP) and 90% (POCP) of the impacts of the Duni tissue napkin on the German market. This impact is lower or equal to that of Dunicel on the German market, but it should be noted that an infinite number of uses is unrealistic.

D.2.2 Size of reusable napkins

In the base case, the size of the single-use napkins were assumed to be about 40x40 square centimetres, while reusable napkins were assumed to be somewhat larger (45x45 square centimetres). Here, this assumption is analysed by recalculating the results for the napkin alternatives listed in Table 10.

Table 10: Alternative cotton napkins included in the sensitivity analysis of the size of reusable napkins.

	Weight (g)	**Size (cm x cm)**
Cotton 35x35	25.9	35x35 (36x36*)
Cotton 40x40	33.6	40x40 (41x41*)
Cotton 45x45 (base case)	42.3	45x45 (46x46*)

* To calculate the total weight of the napkin, it was assumed that the sides were folded by 0.5 cm per edge.

The results for all environmental impact categories for the German market relative to the Duni tissue napkin are presented in Figure 21.

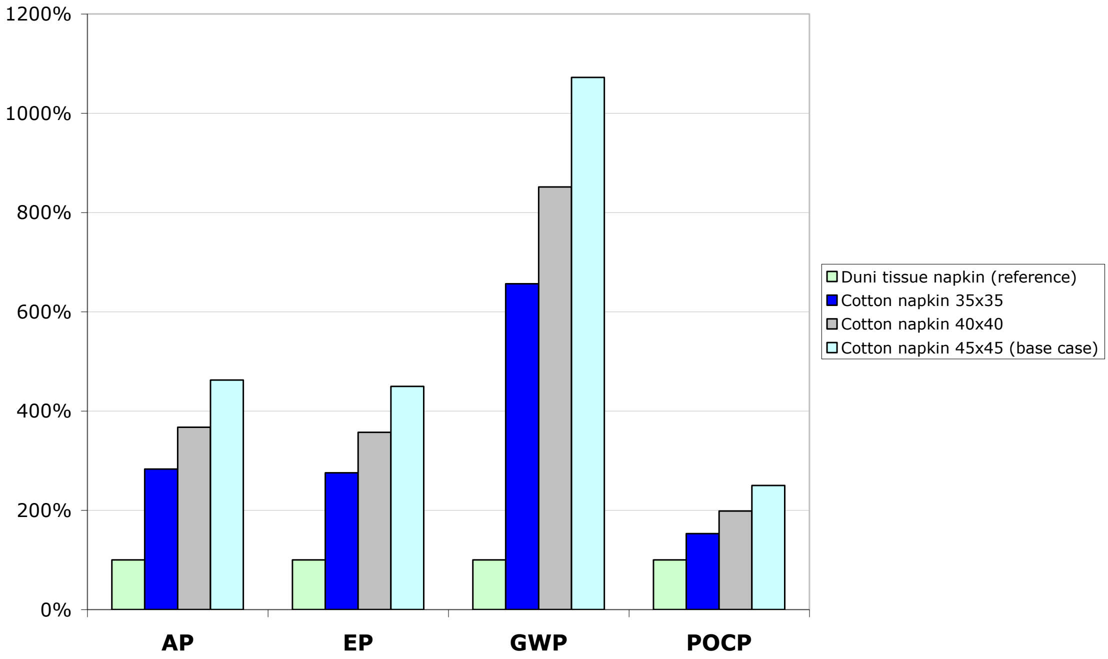

Figure 21 Sensitivity analysis of the importance of the assumed weight of the cotton napkin on the German market. The included sizes are 35x35, 40x40 and 45x45 square centimetres. The results of the base case Duni tissue napkin has been set to 1 (100%) in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the results are very much dependent on napkin size, as the weight of the napkin is related to the square of the length of the napkin side. A decreased size leads to a reduced raw material use, transports, laundry and waste management causing a total reduction of almost 40% in all impact categories if the napkin is 35x35 instead of 45x45 square centimetres.

D.2.3 Energy use for weaving

In the base case, an electricity use of 10.6 MJ/kg fabrics was used for weaving. Here, it was assumed that only 5.4 MJ/kg fabric was used for the cotton napkin on the German market. The results for all impact categories relative to the Duni tissue napkin are presented in Figure 22.

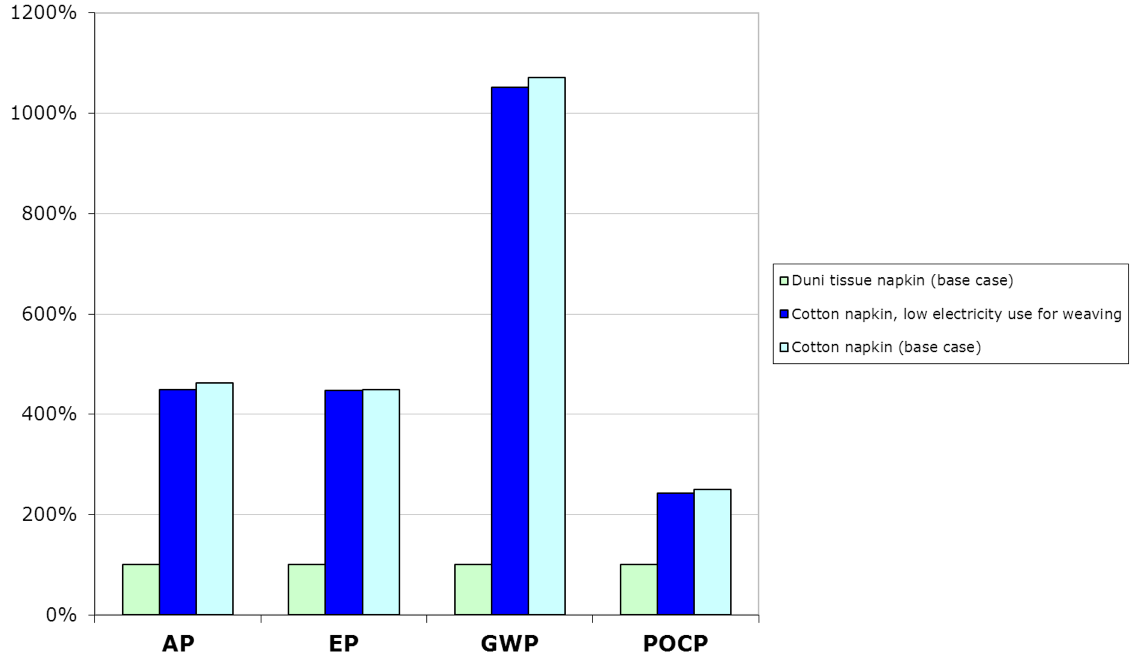

Figure 22 Sensitivity analysis of the importance of the electricity use at weaving. The base case uses 10.6 MJ/kg fabric, and a new option has been added that only uses 5.4 MJ/kg fabric. The results of the base case Duni tissue napkin has been set to 1 (100%) in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The figure shows that the assumption regarding electricity use at weaving has a minor influence on the total results. One of the reasons for this is the dominance of the laundry life cycle phase for reusable napkins for some impact categories.

D.2.4 Low-carbon electricity at laundry service

In the base case, a country-average supply mix of electricity was used at laundry service at each market. In this sensitivity analysis electricity produced from low-carbon energy sources such as nuclear power and renewable energy sources is modelled for the cotton napkin on the German market. The Duni napkins have been included for comparison.

The result for all impact categories relative to the Duni tissue napkin are presented in Figure 13.

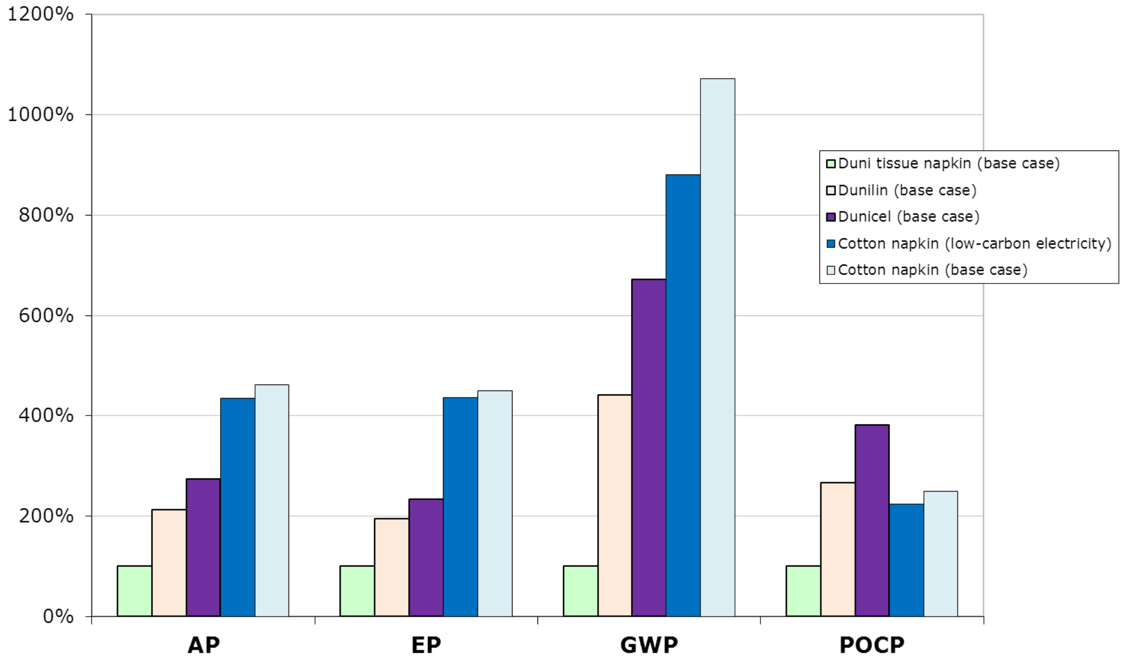

Figure 23 Sensitivity analysis of the importance of the assumed electricity mix at laundry service. The base case uses the German average supply mix, and the new option uses low-carbon electricity. The results of the base case Duni tissue napkin has been set to 1 (100%) in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the GWP impact category is quite sensitivity to the assumed electricity mix at laundry service at the German market. The other impact categories are not affected as much. The same result is expected for the British market, but the difference should be lower on the Swedish market, as the national electricity mix is less dependent on fossil fuels.

D.2.5 Methane emissions at landfill

In the base case, it was assumed that 227 grams of methane is formed per kg of cellulose deposited at landfill. To check the impact of this assumption on the results, it was assumed that 200 g/kg ("low methane emissions") or 250 g/kg ("high methane emissions") is formed. The results are shown for GWP on the British market in Figure 24.

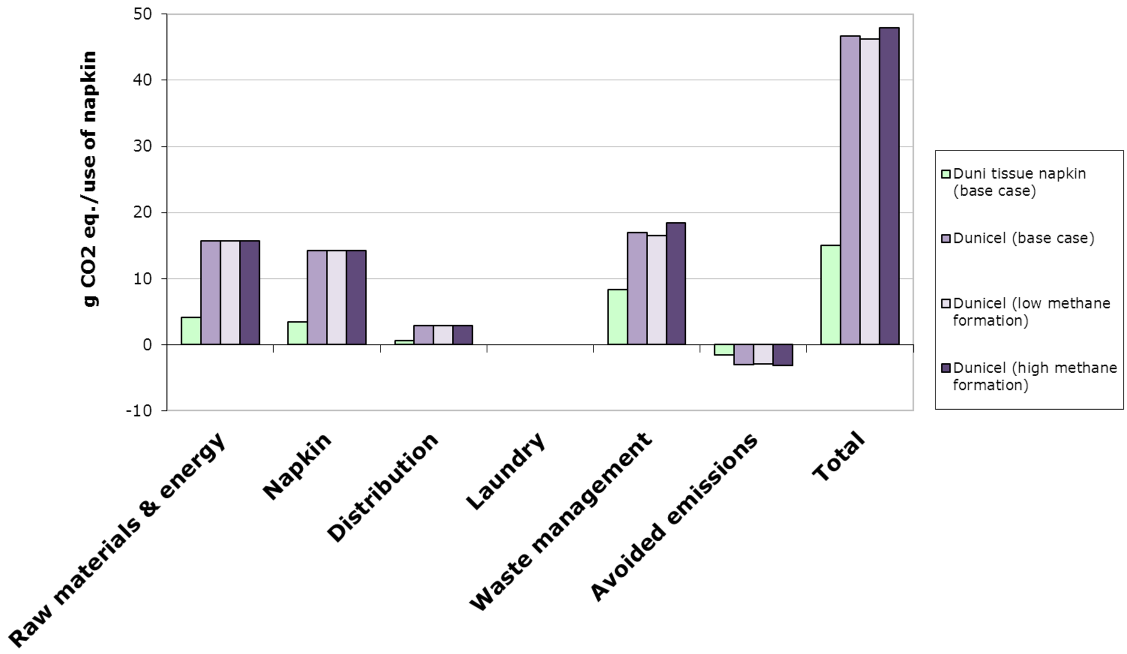

Figure 24 Sensitivity analysis of methane formation at landfill at the British market. The base case is supplemented by two cases where a lower and higher methane formation rate has been assumed. The base case Duni tissue napkin is included for comparison.

The results show that a slight variation in the assumed amount of methane formed at landfill has a limited impact on the total results for Dunicel on the British market. The effect on other environmental impact categories should be small as methane is mainly a greenhouse gas.

D.2.6 Marginal electricity

In the base case, a country-average supply mix of electricity was generally used throughout the product life cycle. In this sensitivity analysis, electricity produced from hard coal was used instead, where possible, to simulate a simplified consequential LCA approach; see Section A.1. The base case Duni tissue napkin is included for comparison.

The results are shown in Figure 25, which corresponds to the base case results in Figure 4 on page 6.

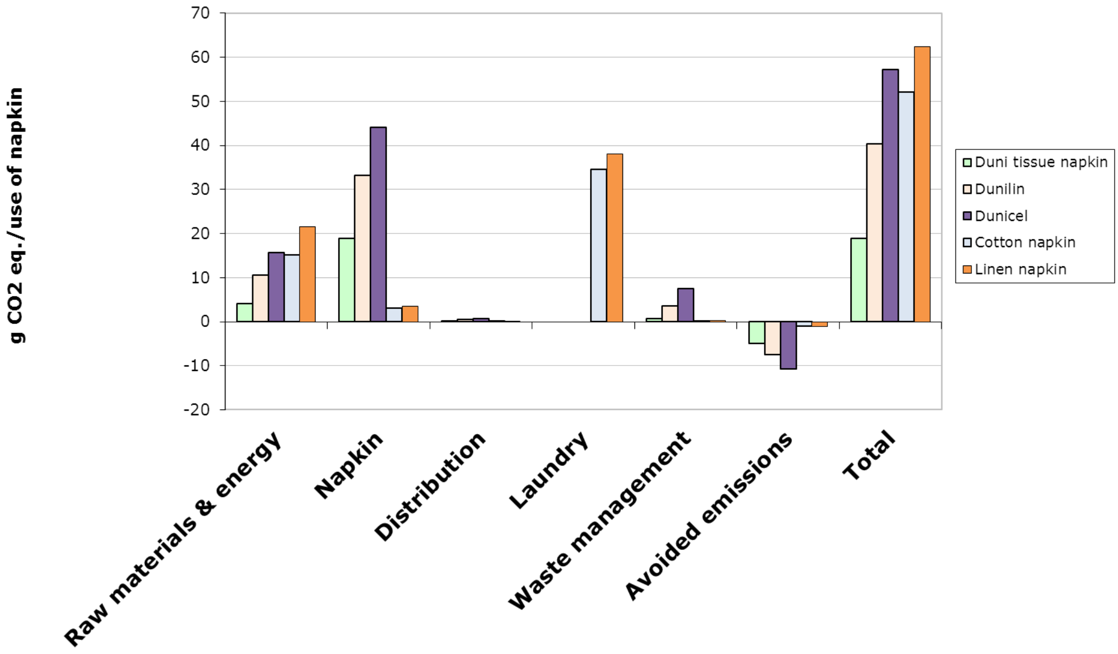

Figure 25 Sensitivity analysis using a marginal electricity approach (hard coal) for all napkin systems on the German market.

The results show that the impact in terms of global warming potential increases for all napkins systems compared to the base case (Figure 4 on page 6). With a marginal electricity approach, the potential climate impact per use of Dunicel napkin is in the same order of magnitude as the reusable napkins. The impact of the Duni tissue napkin and Dunilin napkin remains somewhat lower on the German market.

The largest individual differences are the following:

- Raw material and energy for the linen napkin. This is due to the large difference in carbon footprint between power from hard coal and the French grid mix (mainly nuclear power).
- Napkin production for the three Duni napkins. This is due to the large difference in carbon footprint between power from hard coal and the Vattenfall power mix (mainly nuclear power and hydro power).

The conclusion from this sensitivity analysis is that a different LCA approach may affect the results of the study.

D.2.7 Best case scenario for reusable napkins

As of yet, only one parameter has been checked at a time. Here, the following best-case assumptions have been made for the reusable napkins:

- High number of wash cycles for reusable napkin – 60 cycles (see Section D.2.1)
- Small reusable napkin size – 35x35 cm^2 (see Section D.2.2)
- Low energy use for weaving process – 5.4 MJ/kg fabric (see Section D.2.3)
- Low-carbon electricity at laundry service (see Section D.2.4)

The results are shown in Figure 26.

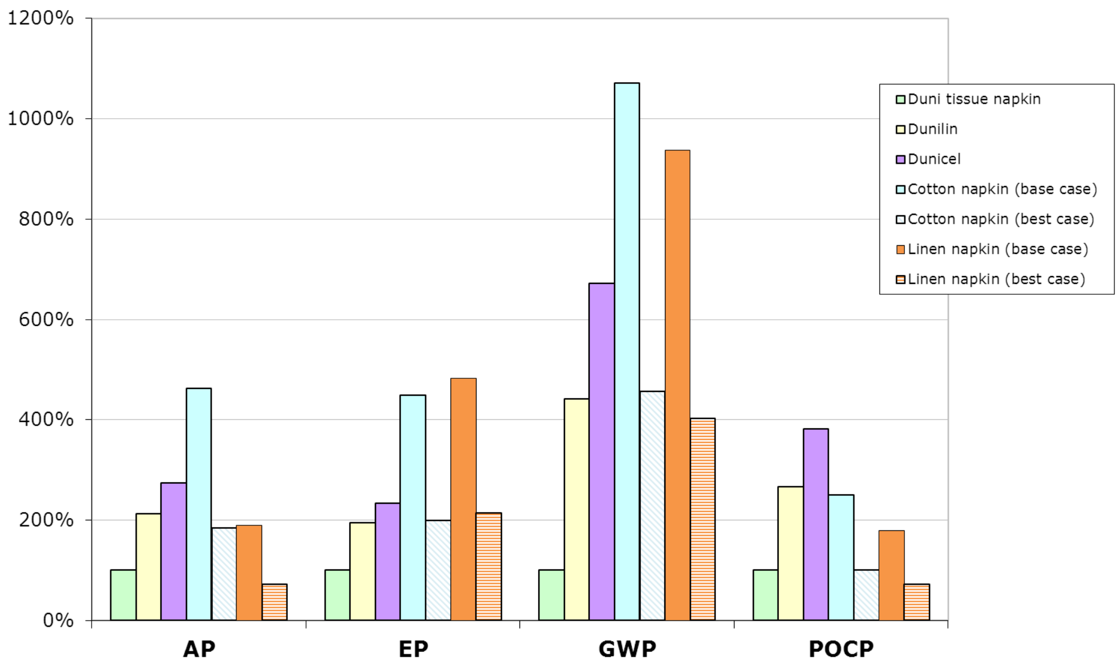

Figure 26 Sensitivity analysis using all best-case assumptions for reusable napkins (German market). The results of the base case Duni tissue napkin has been set to 1 (100%) in each impact category. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the combination of the best-case assumptions for reusable napkins has a major impact on the results. If the reusable napkins are very small, the napkins are used a very large number of times during its life cycle, the weaving process is energy-efficient and if low-carbon electricity is used at laundry service, the environmental impacts of the reusable napkins are comparable or smaller than those of Dunilin and Dunicel (on the German market).

The Duni tissue napkin is still the one with the lowest impacts for eutrophication and climate change, while the linen napkin is comparable when it comes to acidification and photochemical oxidant creation.

D.3 Completeness check

A completeness check was carried out to see if the data gaps of the study could potentially have an impact on the results and the conclusions drawn from them. The data gaps were analysed one by one by making "worst case" assumptions on the environmental impact of the data gap, and checking how it would impact the total results in all environmental impact categories. The data gaps, assumptions made and results can be found in Table 11.

Table 11: Completeness check of data gaps in terms of global warming potential.

Data gap	Affected systems	Assumption	Effect on total results	May affect conclusions?
Chemicals for paper production and converting	Duni tissue napkin, Dunilin, Dunicel	0.7 g of a chemical with high emissions[12]/ Dunicel	Up to 3% impact on different categories for Dunicel	Yes
Material losses during weaving	Cotton napkin, linen napkin	2% material losses during weaving	Up to 2% increased impact in different impact categories for cotton napkin	Yes
Sizing agent used at weaving	Cotton napkin, linen napkin	225 g modified starch / kg of textile	Up to 4% increased impact in different impact categories for cotton napkin	Yes
Emissions to water during weaving	Cotton napkin, linen napkin	COD of 35 mg PO_4^{3-} eq/g sizing agent	< 1% effect on EP, no effect on AP, GWP, POCP for cotton napkin	No
Detergent, bleach, starch and softener at laundry facility	Cotton napkin, linen napkin	Production of 20 g of zeolite powder / kg of laundry	Large effect on AP, EP, GWP and POCP for cotton napkin	Yes
Transport packaging for distribution of textile napkins	Cotton napkin, linen napkin	Production of 25 g plastic foil (PP) / kg napkin distributed	About 1% impact for POCP, < 1% for AP, EP and POCP for cotton napkin	No
Transport packaging for return transport from laundry service	Cotton napkin, linen napkin	Production of 25 g plastic foil (PP) / kg napkin transported to laundry	Large effect on AP, EP, GWP and POCP for cotton napkin	Yes

The table shows that several of the data gaps may significantly affect the results. This could work both in favour of single-use napkins and for reusable napkins.

For single-use napkin, the data gap that could prove to have significance for the total results is the production of some chemicals. This data gap corresponds to the chemicals for which no reliable and geographically and technically relevant sources of production data could be found.

For reusable napkins, more data gaps were identified than for single-use napkins. This was expected as these are estimated alternative products modelled in order to compare the environmental performance of the use of single-use napkins. Data gaps regarding the laundry stage of the napkins were found to be significant as the environmental impacts of washing a napkin is directly related to the use of a napkin, while the production of a napkin only occurs one time per 40 uses of a textile napkin.

[12] The chosen chemical was hydro-cyanic acid since it was found to have high emissions in all environmental impact categories. The chemical itself is, however, not used in the products covered by this study.

D.4 Consistency check

The consistency check is performed in order to answer the question: *is the modelling and methodology appropriate for the goal and scope of this study?*

The goal of this study was to calculate and compare the environmental impacts of six table napkins, while serving as a starting point for the development of environmental product declarations (EPD) for the Duni paper napkins. The methodology was therefore chosen primarily to follow the general principles and practice of the International EPD System (SEMCo, 2010). No valid product category rules were found for paper napkins why the general programme instructions and updated product category rules of other types of paper products were used as references.

The data sources, system boundary, etc., of paper napkins were the same, why there should be no problem in comparing the total results of these napkins. A problem with the system boundary of the International EPD System is that is that waste management and avoided emissions due to generated electricity and heat are normally not included. These processes were thus added in a separate life cycle stage for all napkins. The functional unit was defined as "one use of a dinner napkin at an average restaurant" to have a common unit of comparison for the different napkin types.

Section A.5 lists other potential issues for the comparability of the systems. Data gaps are treated in Section D.3, where it was shown that several data gaps may have an impact on the total results and the conclusions. The data gaps mainly concern the reusable napkins as no specific data was available for these napkins. The data gaps should, however, all work to make the total results an underestimate of the total impact of the reusable napkins.

Another area where it could be a problem to have specific data for single-use napkins, but not for reusable napkins is the site-specific versus national average electricity production. The single-use napkins benefit, for instance, from a paper production where the purchased electricity causes low emissions of carbon dioxide. The reusable napkins could benefit greatly from buying specific electricity for laundry service as seen in Section D.2.2, but also for cultivation and weaving, but since no specific data was available, a country-average electricity mix has been used.

Based on the possible inconsistencies identified during the life cycle inventory and the interpretation of the results, the methodology and modelling should be sufficient to provide an indicative comparison between single-use and reusable napkin and as a first step towards EPD:s of Duni paper napkins. The results should, however, preferably be interpreted and communicated conservatively.

D.5 Dominance analysis

In the dominance analysis, the results are analysed in terms of which life cycle stages are dominant in contributing to the total environmental impacts of the different napkins. The raw materials and energy life cycle stage of Dunicel are investigated separately to determine which component is the main contributor to the environmental impact.

D.5.1 Life cycle of all napkins

Here, the results were analysed in terms of which life cycle stages were dominant in contributing to the total environmental impacts of the different napkins. Results per life cycle stage for all environmental impact categories for the three markets are available in Section 3 or Appendix C.

Duni tissue napkin

For the Duni tissue napkin, the most important life cycle stage is the production of raw materials and energy for almost all impact categories and markets. This is explained by an electricity mix based mainly on nuclear power and hydro power during tissue paper production and low energy use at converting. The exception is GWP for the British market, where waste management is the most important life cycle stage. This is caused by the high rate of landfill and the related emissions of methane during decomposition of the cellulose.

Dunilin

As for the Duni tissue napkin, the most important life cycle stage is the production of raw materials (pulp, glue, etc.) and energy for most impact categories and markets, but the life cycle stage "napkin" is also important for GWP. This difference is due to rather higher energy use at converting compared to the Duni tissue napkin. On the British market, the waste management is also important for GWP by the same reason as for the Duni tissue napkin.

Dunicel

As for the other paper napkins from virgin raw materials, the most important life cycle stage is the production of raw materials and energy. Dunicel is a quite heavy napkin – its weight is more than double that of Dunilin and about three times that of a Duni tissue napkin. The difference in weight is mainly due to the content of filler and glue, which is added at converting in Germany. The raw materials and energy life cycle stage is further analysed in Section D.5.2.

As in the case of Dunilin, the converting requires much more energy (electricity and natural gas) for Dunicel than for the Duni tissue napkin, why this life cycle stage contributes significantly to GWP.

Unlike the other napkins from virgin raw materials, the waste management life cycle stage is important for GWP on the German and Swedish markets. This is due to the incineration of the glue, which causes emissions of fossil carbon dioxide.

Cotton napkin

For the cotton napkin, the production of raw materials is the most important life cycle stage for AP, EP and POCP, despite that the emissions from raw material production are divided per number of uses of the napkin before disposal (40 in the base case). For GWP, the emissions due to energy use at laundry are dominating the total impact due to the use of natural gas and electricity at laundry service. Laundry is also significant for EP due to the emissions to water and from electricity production.

Linen napkin

For the linen napkin, the production of raw materials is the most important life cycle stage for EP. For AP and GWP, however, this life cycle stage is less important due to the assumption that fibre processing takes place in France, which has a nuclear power-based electricity supply mix. For these two environmental impact categories, the energy use at the laundry facility and raw material and energy is the most important. Laundry is also significant for EP due to the emissions to water and from electricity production.

D.5.2 Raw material and energy of Dunicel

In order to provide environmental support for future product development, the life cycle stage "raw materials & energy" was analysed separately for Dunicel divided into the following sub-life cycle stages: pulp, glue, chalk, energy carriers, transport packaging and other chemicals. The result is presented in Figure 27 and Figure 28 for global warming potential and eutrophication potential.

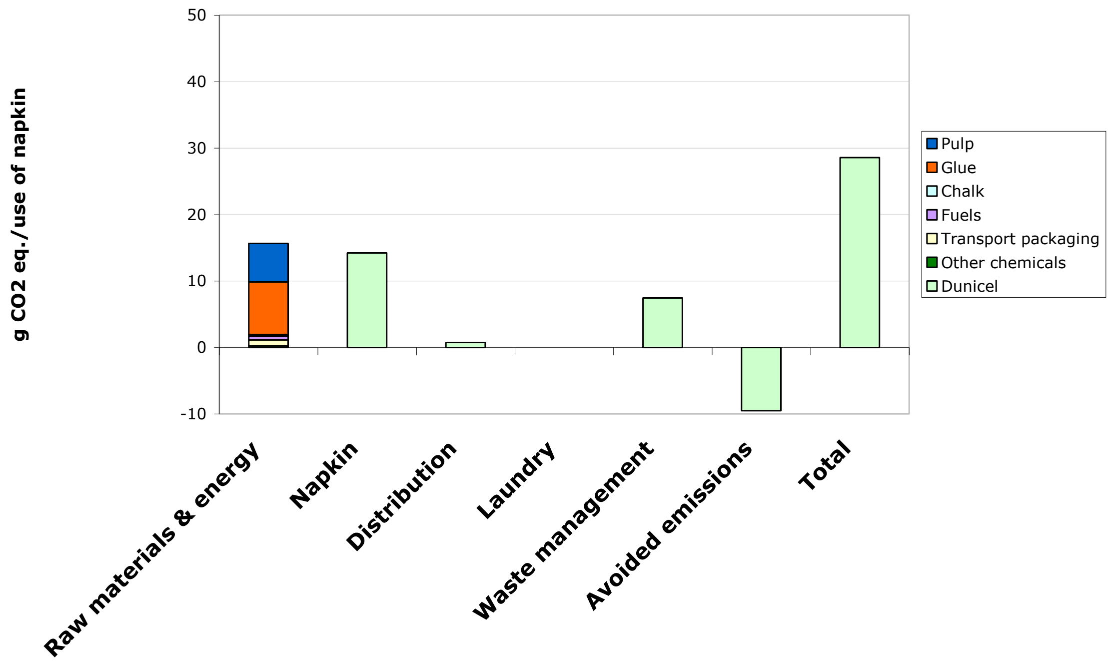

Figure 27 Global warming potential for Dunicel on the German market (unit: g CO2e/use of napkin). The life cycle stage "raw materials & energy" has been divided into its sub-processes: pulp, glue, chalk, energy carriers, transport packaging and other chemicals.

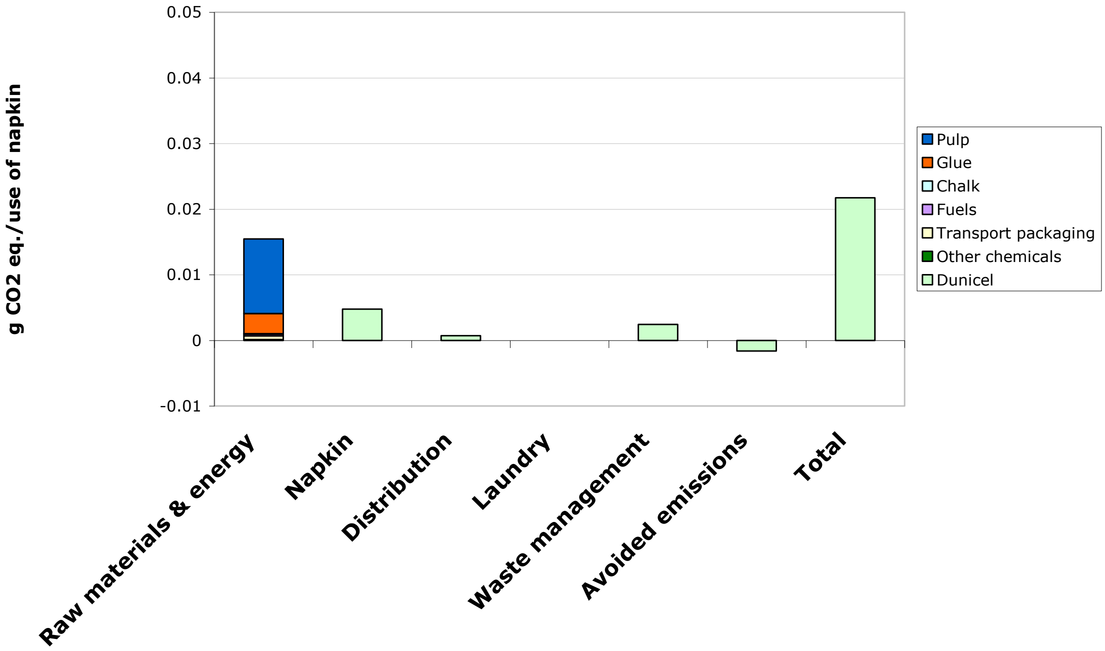

Figure 28 Eutrophication potential for Dunicel on the German market (unit: g PO43-e/use of napkin). The life cycle stage "raw materials & energy" has been divided into its sub-processes: pulp, glue, chalk, energy carriers, transport packaging and other chemicals.

The results show that the production of glue dominates the global warming potential of raw materials and energy production, followed by the production of pulp. For eutrophication potential, the dominating sub-life cycle stage is pulp production, followed by glue production.

Any product development aiming at reducing the environmental impacts from the production of raw materials should thus focus on pulp production and the production of glue.

Appendix E References: Personal communication

References, personal communication

CJ (2010), Personal communication with Christel Johansson, Environmental & Quality Manager, DSV Road AB, Helsingborg, Sweden. May 2010.

CL (2010), Personal communication with Catarina Ljungberg, Environmental Manager, SCA Östrand pulp mill, Sweden. January 2010.

EG (2010), Personal communication with Elisabeth Gierow, Duni AB, Malmö, Sweden.

ET (2009), Personal contact with Eva Thuresson, Södra Cell International AB, Sweden. December 2009.

HJS (2010), Personal communication with Hans-Joachim Stahmeyer, Quality and Environmental Manager, Duni GmbH, Germany. January-March 2010.

MF (2009), Personal communication with Magnus Fransson, Duni AB, Malmö, Sweden. December 2009.

PL & MJ (2010), Personal communication with Peter Lundin and Monica Johansson, Rexcell Tissue & Airlaid AB, Skåpafors, Sweden. January-February 2010.

WB (2010), Personal communication with Wilbert Baerwaldt, Duni AB, Sweden. January-February 2010.

Appendix F Critical review report

Kim Christiansen, Danish Standards, Denmark
Randi Dalgaard, 2.-0 LCA consultants, Denmark (rad@lca-net.com)

Review statement on the following LCA report:

Life cycle assessment of premium single-use and reusable napkins for restaurant dinners. Authors: Kristian Jelse & Jenny Westerdahl

Review procedure

The review was performed in the period from 8 July 2011 to 26 October 2011. The review was started up by Kim Christiansen from Danish Standards, who commented on the first version of the report. The review was hereafter taken over by Randi Dalgaard from 2.-0 LCA consultant, who only commented on the authors' answers to questions already raised by Kim Christiansen. The reviewers have received three different versions of the report.

Overall statement

This critical review is carried out in accordance with ISO 14040/44. This critical review is NOT a panel review. According to ISO 14044, section 6.1:*"…a panel of interested parties shall conduct critical reviews on LCA studies where the results are intended to be used to support a comparative assertion intended to be disclosed to the public."* In the current LCA study different kinds of table napkins are compared, thus a critical panel review has to be carried out if the report will be disclosed to the public.

The report fulfills the requirements of ISO14040/44 except for lack of the panel review as described above.

Comments/answers from reviewer/authors

Reviewer: Why do you not use the phases of the LCA - goal and scope is included but the others are merged into "results" and "discussion" and/or covered by appendices (also in another order)
Authors: The format of the report has been adjusted to the target audience (non-LCA experts). To clarify the report structure, the correspondence between the chapters and the different phases of an LCA has been included in the introduction.

Terminology

Reviewer: I recommend to use the terminology of ISO 14040 and 14044 consistently. Examples:
Boundaries = boundary (there is only one)
Authors: OK. The report has been updated.

Reviewer: Impact = impacts; if it is the overall environmental impact then weighting is needed
Authors: OK. The report has been updated.

Reviewer: Phases = stages; stages of the life cycle; phases of the life cycle assessment (there is a mistake in figure 1 of 14040 – please refer to the body text)
Authors: OK. The report has been updated.

Reviewer: Waste management = End-of-life management
Authors: In the report, "waste management" is used as a comprehensive term for of all types of treatment of waste (collection, transportation, handling, incineration, landfill, recycling…). End-of-life management in ISO (cf. introduction of ISO 14044:2006) appears to exclude recycling processes as the two are listed separately: "…throughout the product's life cycle from raw material

acquisition, through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)".

Specific comments

Reviewer: p.3 "Linen" is not a material per se e.g. it can be based on cotton. Use another term.
Authors: Linen may refer to different things. In the report, we refer to the material "linen" (Swedish: linne; Danish: hørlærred) made from the plant "flax" (Swedish: lin; Danish: almindelig hør), not as a general term for domestic textiles. This has been clarified the first time linen is mentioned in the report (cf. introduction) as well as in the overview of the goal and scope and the detailed goal and scope.

Reviewer: p.3. Add text explaining that national electricity mix of Germany, Sweden and United Kingdom is only relevant for those processes actually taking place in these countries i.e. list also in the introduction where raw material acquisition, production (of paper and of paper products; of cotton and of cotton products; of "linen" and of "linen" products), use (of final products) and end-of-life.
Authors: This information is already available on page 4 and 5, why I don't agree that it should be duplicated on page 2 (introduction). The paragraph "The investigated market segment ..." has been moved to the goal and scope (page 3).

Reviewer: p.4 When doing comparative LCA the data quality should be the same. When producers of the alternatives are not involved in the study this requirement is typically impossible to fulfil. Therefore worst case or conservative assumptions as well as sensitivity (and uncertainty) analysis shall be performed. This should be stated clearly in the goal and scope definition.
Authors: OK. The following text has been added "No manufacturer of reusable napkins has been involved in the study. As an attempt to avoid overestimations of the environmental impacts from these products, conservative assumptions have been made where possible, and a sensitivity analysis has been performed to check important parameters."

Reviewer: p.4 Some information on the functional unit should be added to justify that one paper napkin only is used. Will 10-20 grams of paper contain the same amount of food or drinks as 40 grams of cotton or "linen"? In annex A this is made as an assumption, but it is not a justification per se, and the sensitivity of this assumptions should be tested. The weight is the parameter determining the impacts.
Authors: The paper napkins included in the study are all large and marketed as possible textile napkin-replacements at restaurants at the three markets ("premium"). Simpler 1- or 2-ply (layers) napkins that may be found at e.g. fast-food restaurants or cafeterias have not been included in this study. To highlight this, the title of the study was changed from "Life cycle assessment of single-use and reusable dinner napkins on the professional market" to "Life cycle assessment of premium single-use and reusable napkins for restaurant dinners". For this application, I would argue that the absorption capacity of the different napkins is irrelevant for the function provided by the napkin. For reference, the Duni product catalogue for the professional market is available here: http://www.duni.com/Global/Hotel_Restaurant/Catalogues/SV_2011_Professional.pdf
In the professional market, the decision-maker regarding what napkins to use is usually not the visitor, but the restaurant itself. They have a choice between the napkins included in this study.
The assumed size (and thus weight) of the cotton napkin was checked in the sensitivity analysis and has a large impact on the results. This is also true for the assumption on the number of times a napkin is reused during its life time. This is highlighted in the conclusions. I have also added the following text in the introduction to the conclusions: "No manufacturer of reusable napkins has

been involved in this study, why sensitivity analyses were performed on key assumptions such as napkin size and the number of times a reusable napkin is washed during its life time".

Reviewer: p.4, 4th paragraph. "Linen" is based on "flax" which is "newzealandsk hør" (Gyldendals ordbord)? Better use the term "flax" as linen can cover also cotton based products.
Authors: The material made from the flax plant is called linen (see above). This is now explained the first time the term linen is used.

Reviewer: p.4 The choice of impact categories is neither explained nor justified. In the annex a statement of lower data quality for some other impact categories is included, but this is not a valid argument as the data quality will depend a lot on the product under study – and more important – data quality cannot be used to exclude an impact category that is at the core of a specific product system as for example land use for cotton and flax; at least the sensitivity analysis should include an estimate are you should argue that including land use will only confirm the findings from the other impact categories that recycled napkins have higher impacts – and some good arguments for this.
Authors: As the studies aimed at serving as a basis for EPDs, the categories included in the International EPD System were used (with the exception of ozone depletion). As no specific data were available for the production of reusable napkins, the data quality for land use, water, etc., were considered too low to be possible to include. This limitation of the study is mentioned in the overview of goal and scope, the discussion, the conclusion, the recommendation and the goal and scope (Appendix A). The goal has been rephrased to indicate that only four environmental impact categories are included.

Reviewer: p.6 As a PS – I have asked the International EPD System on the status of exclusion of the EoL and they stated that this is only the case for less than 20% of the PCR's; I suggest you check also.
Authors: One of the authors of this study is currently holding the secretariat of the International EPD System during Joakim Thornéus parental leave (June–December 2011). Based on this insight into PCR development, product end of life is normally included in consumer-oriented EPDs, but system expansion to include "avoided emissions" is only supplied as additional information.

Reviewer: p.7 Chapters 3.1, 3.2 and 3.3 should include a table or figure showing were the different processes (stages) of the life cycle takes place – this is not clear. Is paper produced in UK or Germany or Sweden? Or is it only the paper product? Or is it only used and disposed of in the 3 countries? If paper is produced in Sweden and paper products produced in Germany for all 3 user markets then this should be made very clear. Due to the higher level of landfilling in UK there might still be a reason for separating based on the use and end-of-life stages, but I am not sure. Sorry for not being able to read between the lines. According to A.7.2 pulp and paper is produced in Sweden, so electricity should be Swedish mix, not Nordic – or at least a justification beyond that data source is Vattenfall.
Authors: The life cycle of the products is identical up until the distribution. This has been highlighted in the goal and scope (overview and appendix A) and the headings 3.1-3.3 have been changed to "Results for use on the German/Swedish/British market".
The electricity mix during use (mainly washing of reusable napkins) and the waste management schemes is the reason for the separation of the three use-markets. The International EPD System allows for use of contract-specific electricity mixes, why this has been used for paper production.

Reviewer: p.7 The basis for normalization should be included also in the body text of the report, not only in the annex, actually most correctly as part of the goal and scope definition.

Authors: The text does not refer to normalization as defined by ISO 1404X. The text has been changed to "environmental impact relative to Duni tissue napkin (100% in each impact category)"

Reviewer: p.7 Uncertainty on the results is not depicted neither in text nor in the figures; no information can be found in the annex. Without an uncertainty analysis – or at least an indication of uncertainties on the data used, the validity of the comparisons is highly questionable.
Authors: A data uncertainty check and additional sensitivity analyses have been added.

Reviewer: p.8 section 3.1.2 shows the " cycle stages" – the present heading is not clear, and my proposal might not be better.
Authors: The names of the headings and the introductory text have been changed throughout Section 3.

Reviewer: p.9 On the choice of Nordic electricity mix versus French electricity mix you need to show that electricity used in Sweden are taken from the Nordic mix and electricity in France from the French mix only. With the opening of the electricity market but also with the limitations of the distribution infrastructure this is not an easy case, but it is important to the overall results. Therefore a sensitivity analysis using e.g. only coal and only wind might support the conclusions even better than choosing an uncertain "existing" energy mix. And this is not mentioning the uncertainties on the US and China energy mixes.
Authors: The sensitivity analysis "low carbon electricity at laundry service" is complemented by a marginal electricity sensitivity analysis. Please note that no Nordic average electricity mix has been used in the model. A Swedish consumption mix has been used for processes taking place in Sweden.

Reviewer: p.9 Is the energy and material consumption for the waste water treatment facility included? Yes according to p. XI – maybe include this information also in the main report?
Authors: OK. This has been added to page 6: "The output water from laundry was assumed to be handled in a medium-sized municipal waste water treatment plant", and further explained in the life cycle inventory analysis (Section B.3.4).

Reviewer: p. 10-15. If I read correct, maybe figures showing only the differences of the stages of the life cycle where there actually are country specific differences (use and end-of-life) should be the only ones differentiated whereas the results for raw material and production should be merged?
Authors: The results for the three end-use markets are intended to be analysed separately, and not to be compared. The two first life cycle phases are indeed the same for all three markets, but when looking at the results for one market, one should be able to tell what part of the environmental impact that arises from raw materials separately from other stages of the life cycle, such as the napkin production.

Reviewer: p.6-17: The conclusion is self-contradicting. In the first main conclusion, it is stated no single answer can be given. In the second main conclusion it is stated Duni has the lowest environmental impact.
Authors: It has been clarified that this conclusion referred to the group of products "single-use napkins" and the group "reusable napkins", and updated with uncertainty from the interpretation: "The results of the study cannot be used to support general statements regarding the environmental superiority of either the product group "single-use napkins" or the product group "reusable napkins". The results and the sensitivity analyses have shown that the results of this comparison depends on the type of napkin product, the size of the napkin, the type of textile used in reusable napkins and what environmental impact category is considered most important by the reader.

Reviewer: In the conclusion it is written: "*The Duni tissue napkin has the lowest environmental impacts of the studied napkin systems for the environmental impact categories considered in this study and for all studied markets. The low weight (7.2 grams) compared to the alternatives is a key aspect.*" I am not convinced this is a robust result. The report now has 6 different sensitivity analyses. Some parameters are shown to be important. This study has many data gaps, and it is difficult to get an overview of the sensitivity analyses. Changing the parameters one by one might not change the results. But what if you choose 'worst case' for all parameters at the same time? For example: 80 washings, one Duni does not equal one reusable (as discussed above), 'low-carbon electricity' etc. Then the results might be different.
Authors: I agree. A best case scenario for reusable napkins has been added, taking most of the sensitivity parameters into account at the same time. The conclusions have been updated accordingly, so please re-read that chapter.

Reviewer: In figure 10, it is shown 'Linen napkin' has a lower GWP compared to 'Cotton napkin' meaning 'Linen napkin' is closer to 'Duni tissue napkin'. Nevertheless, you choose to do the 'napkin-size' sensitivity analysis (Figure 25) on the 'Cotton napkin'. That is a non-conservative choice.
Authors: The use of only the cotton napkin for the sensitivity was made in order to be consistent throughout the sensitivity analyses. The new sensitivity analysis "Best case scenario for reusable napkins" includes both the cotton and the linen napkin.

Reviewer: p.16 As indicated above, I am not convinced that consistent system boundary and methodologies have been used. Using the general practices of the International EPD System is not a quality stamp per se; this has to be justified assumption by assumption and choice by choice. Especially on the functional unit omitting the different material weights in defining the functional unit (i.e. 10 grams of paper can perform the same service as 40+ grams of cotton or flax) needs better arguments. Also the choice of impact categories should be argued based on other studies comparing paper to cotton products, not on assumptions of the EPD scheme, if the goal is to get credibility of the study.
Authors: The goal of the study has been made clearer: "to calculate the environmental impact (in terms of four impact categories used in the International EPD System) of Duni single-use napkins and to compare their performance with that of reusable textile napkins of cotton and linen (made from flax fibres) based on literature and database data". The use of the EPD System as reference for the LCA methodology mainly impacts two aspects of the study:

- Choice of impact categories and characterisation factors, described and justified in Section A.4.
- Attributional LCA methodology, including the use of country-average or specific electricity mix. Described in Section A.1

ISO 14025 and the General Programme Instructions of the International EPD System are based on ISO 14040 and 14044 for LCA calculations. Knowledge of the methodology choices described in the International EPD System is not required to understand this LCA study, as all important methodology choices have been documented and justified.
In some cases, such as the inclusion of avoided emissions at waste management, we went beyond what is normally included in an EPD to improve the comparison between the products. The following paragraph has been added to the discussion and to the section "Comparisons between systems": *Like all sets of LCA methodologies, the general requirements of the International EPD System have their limitations as a reference for the system boundary, included impact categories and other methodological choices. It*

was chosen anyway for its transparency, international accessibility and applicability if Duni would like to proceed with EPDs of their products in the future.

Appendix A and B

Reviewer: (only supplementary to the comments above as the main body text and the appendix A are more a less repetitive – which is OK for communication purposes)
p.III transport packaging is included but no data are found in the report? Found it – it is found in A.7.6.3 but not stated as transport packaging
Authors: The amount of transport packaging is included in Section A.7.1. I added a paragraph regarding data on manufacturing of transport packaging.

Reviewer: p.V the cotton and flax napkins are often collected for recycling (as industrial napkins)
Authors: I haven't seen any statistics or literature reference that points towards this. I asked a colleague who works with systems' analysis of waste management, with focus on waste prevention and product/material reuse. His assessment was that – in Sweden – he knows of no organisation dealing with large amounts of used textiles have a system for such reuse today. I thus believe that the most likely scenario, in Sweden, is that used napkins are collected as mixed waste. Due to lack of information, we have used the same assumption for the other two markets.

Reviewer: p.V there are different methods available for weighting and they are not all based on value judgments; even more important – the choice of impact categories or the exclusion of end-of-life processes in the EPD scheme are also value judgments; you don't need to justify the exclusion of weighting as it is a voluntary element of the impact assessment anyway.
Authors: I would argue that the most common weighting methods are based on value judgements (directly or indirectly), but I changed the text to: "The aggregation of impact categories into a single score – "weighting" – has not been performed as this frequently requires a value judgement of the relative importance of different impact categories. This assessment is left up to the reader." See also ISO 14040:2006, 4.3 "there is no scientific basis for reducing LCA results to a single overall score or number, since weighting requires value choices".

Reviewer: p.VI, A.6 is commented below as part of the comments on the specific methods of interpretation; no further comments here
Authors: OK

Reviewer: p.IX Data from both PE and Eco-invent data bases are used. Is the data quality (and uncertainties) at the same order of magnitude for these different data sources? Do they make the same type of (economic) allocation? A typical recommendation is to choose all data from one database only to avoid differences in assumptions etc. A clarification is needed. (PE International (2006), Umberto et al (2003) and EcoInvent data are used for different processes in the life cycle.
Authors: A data uncertainty check and additional sensitivity analyses have been added.

Reviewer: p.IX Flax is produced in France according to the main text both here it is stated to be a mix of France, Belgium and the Netherlands?
Authors: The unit process for cultivation practices is based on France, Belgium and the Netherlands (literature data). In this study, we have used a French electricity mix for cultivation. In terms of the environmental impact categories included in this study, the French electricity mix is a conservative estimate for the reusable product. This has been clarified in the report (Section B.3.2).

Reviewer: p.X I am not a specialist on flax production so I checked on internet: Flax fiber is extracted from the bast or skin of the stem of the flax plant. The "bark and woody core" referes to paper fibres, not to flax fibres?
Authors: The text is correct, but as its phrasing was somewhat unclear. The text has been adjusted slightly and a literature reference has been added.

Reviewer: p.X 10.6 MJ is not a conservative estimate but an average; going from 5.4 to 47 MJ pr. Kg!
Authors: The 10.6 figure was chosen in order to avoid an overestimation of the impact from weaving in the base case.

Reviewer: p.XI Include table with the actual composition of the energy sources used for the country mix; the qualitative information listed is not enough information to understand the implications of choosing country specific energy mixes.
Authors: As the reference source from IEA is not publically available the exact numbers used in the model cannot be shown in the report. The public electricity production data from www.iea.org has been added to the report instead.

Reviewer: p.XIII The overall GHG results shows that waste management has the same level of emissions as e.g. production of paper and paper products. Therefore the assumption made on waste management should be tested in the sensitivity assessment. Using data from 1999 might add to the uncertainty (which is not assessed).
Authors: The emission of methane from landfill would only be relevant for the results on the British market (where landfill is most common). A sensitivity analysis will be added regarding the emissions of methane.

Reviewer: p.XIV A.7.6.3 is not clear – this is about avoided emissions both connected to incineration of waste and recycling of transport packaging? Why are these two "processes" chosen? What about avoided emissions connected to differences in land use in cultivation of cotton and flax? The choice of what to include and what to exclude should be justified by calculations (estimations) not by assumptions. And
Authors: Section A.7.6.3 refers to avoided emissions due to waste management as a way to account for energy and material generated during waste management to the benefit of other product life cycles. This has been accounted for separately to allow for transparency. No such allocation problems were encountered at other parts of the life cycle; see A.7.8.

Reviewer: p.XV Allocation should be avoided by expanding the systems assessed. You have chosen not to which is OK with ISO 14044. But then choosing different allocation methods for different processes is not justified. If the choice has no impact on the overall results, then it is not important. If it has, your choice could be based on 1) available information 2) impact on overall result. Please be more clear on the justification.
Authors: The section describing allocation methods in site-specific data and important unit processes in database data has been expanded.

Appendix D
C.1.1
Reviewer: The rule of thumb in the Nordic guidelines a.o. is to divide by 2 and multiply by 2 i.e. 80 wash cycles. And then cotton napkin would perform close to tissue. Then you could discuss the likelihood of having napkins going through 80 wash cycles e.g. by contact to a representative of the competing product. And most likely they would state that it would be very unlikely.

Authors: The number of washes was chosen as a likely range of variation. I can't see the value in using 20, 40, 80 for the sake of a typical rule of thumb if 80 washes is very unlikely. If the cotton napkin was reused an infinite number of times, the environmental impact would converge towards the environmental impact from one wash. In the case of GWP for a cotton napkin in Germany, this would be about 30 g CO2e/use of napkin (figure 4), which is still much higher than the tissue napkin, but close to Dunicel. The results caused by an "infinite number of washes" have been added to the sensitivity analysis, including a comparison to Duni tissue napkin and Dunicel.

C.1.2
Reviewer: Add a sensitivity analysis of using the marginal energy (or worst case) namely coal. Hereby the consequential approach to LCA would partly be covered by the study. Most likely the difference between the base cases will not change but it will make the study more robust.
Authors: A marginal electricity sensitivity analysis has been added.

C.1.3
Reviewer: The size of the napkin per se is not as important as the size needed for the function. Do you use 2 paper napkins compared to 1 cotton, the picture changes dramatically. CHECK!!!
Authors: The function of the napkin used at restaurants is not primarily related to the absorption capacity. All napkins included in the study are "premium" napkins, intended to be used as replacements for reusable napkins. Cf. comment related to p. 4.

C.2
Reviewer: Add "significantly" affect the conclusions; then only #5 and #7 are important – although it is not possible to access the actual importance of "large".
Authors: OK. The report has been updated.

C.3
Paragraph 5
Reviewer: The consequences of using low-carbon energy sources and/or renewable energy for cotton napkin should be added to the sensitivity analysis. It is not fair to the comparison the use "beneficial" data to only one alternative and not the other. If the results are intended to be used for a comparative assertion (or even just a comparison) intended to be available to the public, I will strongly recommend a panel of interested parties for the critical review, not only an external expert. The "conservatively" communication is not good enough.
Authors: A marginal electricity sensitivity analysis has been added, and the "low-carbon sensitivity analysis at laundry service" has been updated. The panel review issue is known to the authors and to Duni, who regards this as an "expert review", and not as a "panel review". Due to costs, practical applicability and other reasons, our view is that panel reviews are quite uncommon in current practice LCA today. At this point in time, Duni is satisfied with a single-person review, and any communications will be more in the line of "we have looked into the environmental impact of our products", and not absolute truths regarding the environmental performance of single-use versus reusable products. The first bullet point in the conclusion has been updated to reflect this.

Appendix E
Reviewer: The date of the communication should be added, not only the year.
Authors: OK. As the e-mail conversations usually went back and forth a few times, we have added the months in the list of references.