REPORT

Life cycle assessment of Dunicel table cover and alternative products

Final report

For Duni AB

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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 single-use and reusable table covers. The study has taken place between May 2011 and June 2011 using data from 2009 for the manufacturing processes. The goal of the study was to assess the relative environmental performance of different single-use and reusable table cover options on three different markets. The Duni single-use table cover has been modelled in such a way to simplify the process of creating a certified environmental product declaration (EPD).

The investigated market segment was the professional market (hotels, restaurants and catering) 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 and the waste management scheme.

The study has been performed in accordance with the international standard ISO 14044. (ISO, 2006). The current version of the report has not been critically reviewed by a panel of interested parties, why no comparative assertion should be made to the public regarding the relative environmental performance of the different product systems.

2. Goal and scope

This section provides an overview of the methodology used in this study. Detailed information on the goal and scope, assumptions, data collection procedure, etc., is available in Appendix A.

The goal of this study is to calculate and compare the environmental impact of the table cover options listed in Table 1. The Dunicel table cover is based on data from Duni and a life cycle assessment of Duni table table/top covers (EG, personal communication; Jelse & Westerdahl, 2010). The cotton table covers and top covers are assumed to be used for several seatings before being washed. The life time of a cotton product was assumed to be 40 wash cycles. All products are modelled as white and without print.

Table 1: The table cover options investigated in this study.

	Number of seatings	**Size (cm x cm)**	**Grammage (g/m^2)**	**Weight (g)**
Dunicel table cover	1	130x130	135	228
Cotton table cover	1.5	130x130	220	372
Cotton table cover & Dunicel top cover	5 (table cover), 1 (top cover)	130x130 100x100	220 135	372 135
Cotton table cover & cotton top cover	5 (table cover), 1.5 (top cover)	130x130 100x100	220 220	372 220

The functional unit was chosen as "providing table cover for one seating at an average restaurant" at three markets selected by Duni: Germany, Sweden and the United Kingdom.[1] The results are presented separately for each market.

The study covers the entire life cycle of the products, from forestry or cultivation of cotton 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.

The potential environmental impacts of the systems are calculated in four categories: climate change, acidification, eutrophication and photochemical oxidant creation. Primary energy demand is also presented.

The system boundaries and life cycle phases for single-use table covers of paper are shown in Figure 1.

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

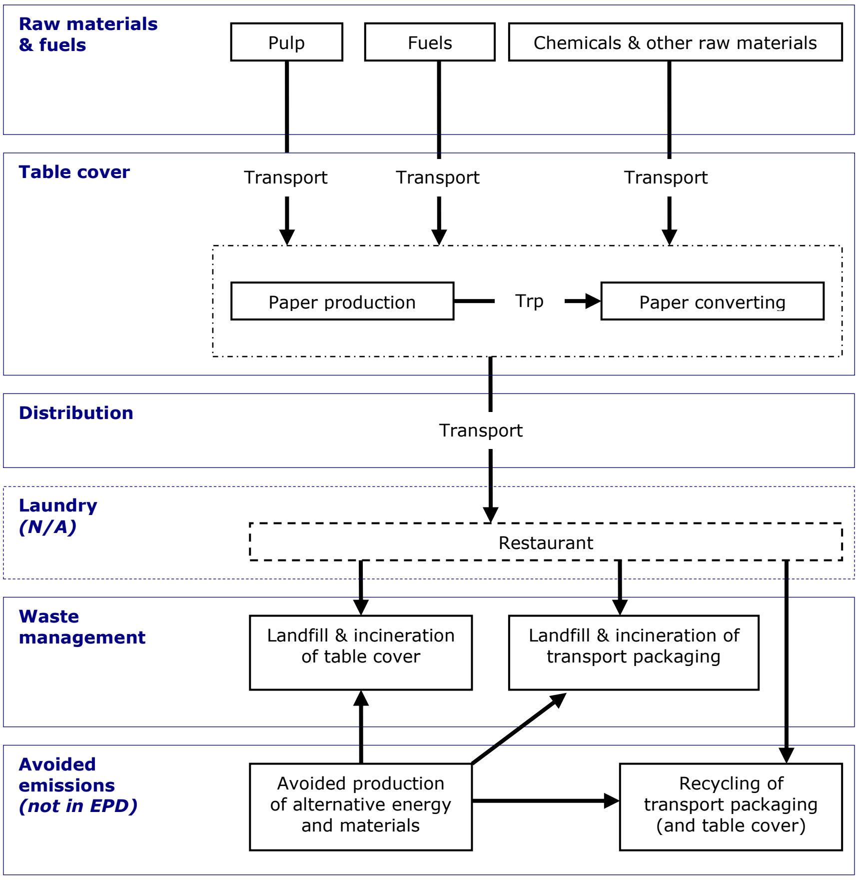

Figure 1 System boundaries and cycle phases for the single-use table and top cover – Dunicel.

For the Dunicel table cover and top cover, the tissue paper is produced in Sweden and transported to a converting site in Germany. After converting, the products were distributed to each market by truck and train and used at an average restaurant.

After use, the Duni products 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. In the sensitivity analysis, an option where the Duni products were recycled was included.

The system boundaries and life cycle phases for the reusable products are shown in Figure 2.

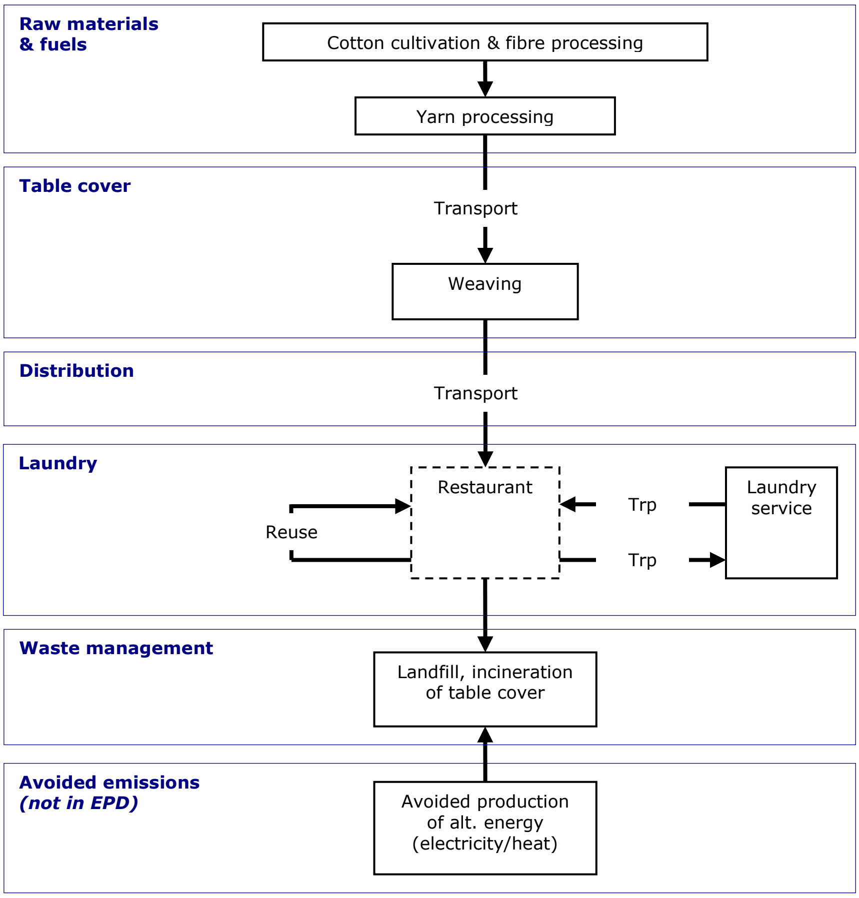

Figure 2 System boundaries and life cycle phases for the reusable products: cotton table/top cover.

Cotton cultivation and fibre processing was assumed to take place in the United States and in China. Weaving took place in Europe before being distributed to one of the three markets by truck.

The reusable products were assumed to be used during either 1.5 or 5 seatings before washing and they were assumed to be washed 40 times during its life cycle. The material attributed to one use of a reusable table cover is therefore between 1/200 and 1/60 depending on the number of times it is used between each wash. After being used 40 times, the textile table covers were assumed to be collected together with the mixed municipal solid waste at each market.

The life cycle phase "avoided emissions" has been included for both single-use and reusable products 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 product systems. This life cycle phase 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 provides the main results of the study, divided into three markets: Germany, Sweden and the United Kingdom. Further figures are presented in Appendix B.

All results are calculated per functional unit – "providing table cover for one seating at an average restaurant" ("per seating") – and thus the washing and reuse of cotton products is accounted for in the results.

3.1. Results, Germany

3.1.1. All impact categories, compared to Dunicel table cover

The results for all systems on the German market are presented in Figure 3. The results are presented as relative to the Dunicel table cover, i.e. the result of Dunicel table cover has been set to 100% in each impact category. Please note that the figure does not imply the relative importance of different impact categories.

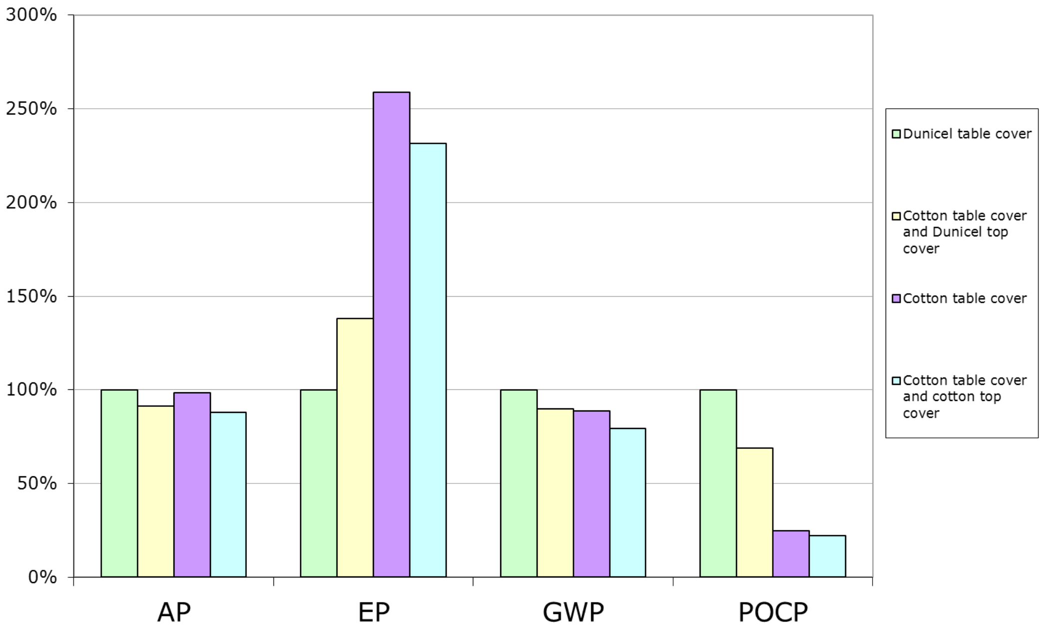

Figure 3 Environmental impact of the four table cover systems on the German market compared to the Dunicel option. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the four studied table cover systems are relatively equal with regard to acidification (AP) and global warming (GWP) on the German market. For eutrophication (EP) the two systems with single-use table covers cause less impact than the systems using only cotton table covers, while for photochemical oxidant creation (POCP) the relation is the opposite with the systems using cotton table covers causing less impact than the systems with single-use table covers.

3.1.2. Selected impact categories, per life cycle phase

This section presents the same results as before, but divided into the six life cycle phases as defined in Section A.3. The results for the German market are presented for global warming in Figure 4.

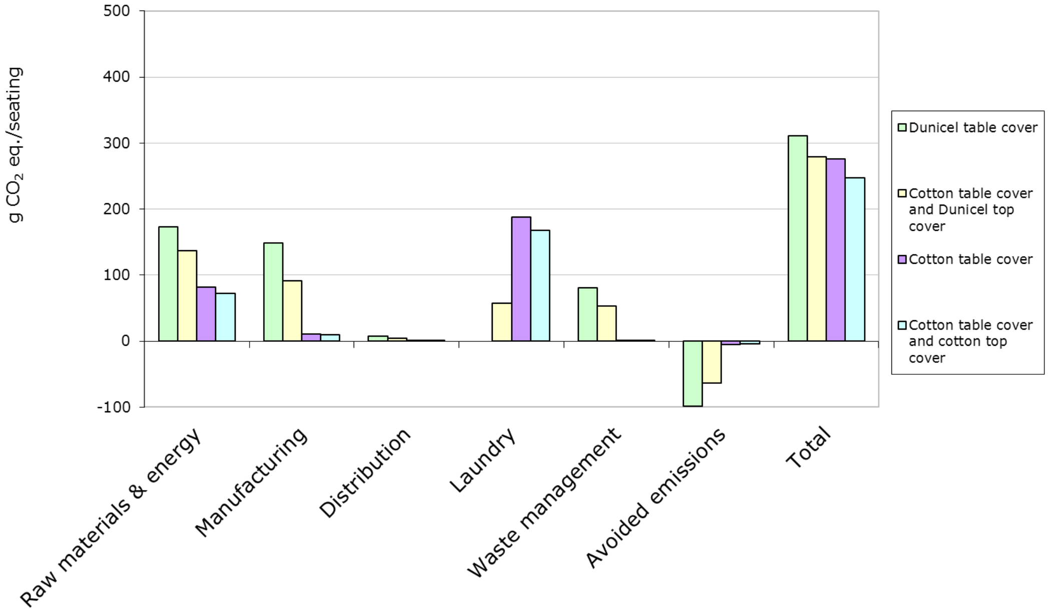

Figure 4 Global warming potential for the four table cover systems on the German market (unit: g CO_2e/seating).

As the results show when divided per life cycle phase, the emissions of greenhouse gases for the Dunicel table cover mainly come from the production of raw materials and energy and from the manufacturing of the table cover, while energy generated during waste management which replaces energy from the German grid stand for the largest emission saving (see avoided emissions). For the system using a cotton table cover in combination with a Dunicel top cover, the emissions of greenhouse gases is slightly less than for the Dunicel table cover option, since the reduced amount of material used saves more emissions than is generated by the laundry process for the cotton table cover.

For the two systems with reusable cotton table/top covers, the main emission of greenhouse gases comes from the laundry followed by emissions from the production of raw materials and energy. The emissions from the laundry are caused by the use of natural gas and electricity at the laundry facility. As significantly less materials is needed for each use of a cotton table cover compared to a Dunicel table cover, less energy is produced from the waste management why the avoided emissions are lower for the reusable table covers than for the single-use table covers.

The contribution of the distribution transport is small for all table covers compared to the other life cycle phases.

To contrast these results, the results with regard to eutrophication (EP) are plotted in Figure 5. The eutrophication impact category might be quite different from global warming, as it is not as dependent on what type of electricity is used as global warming.

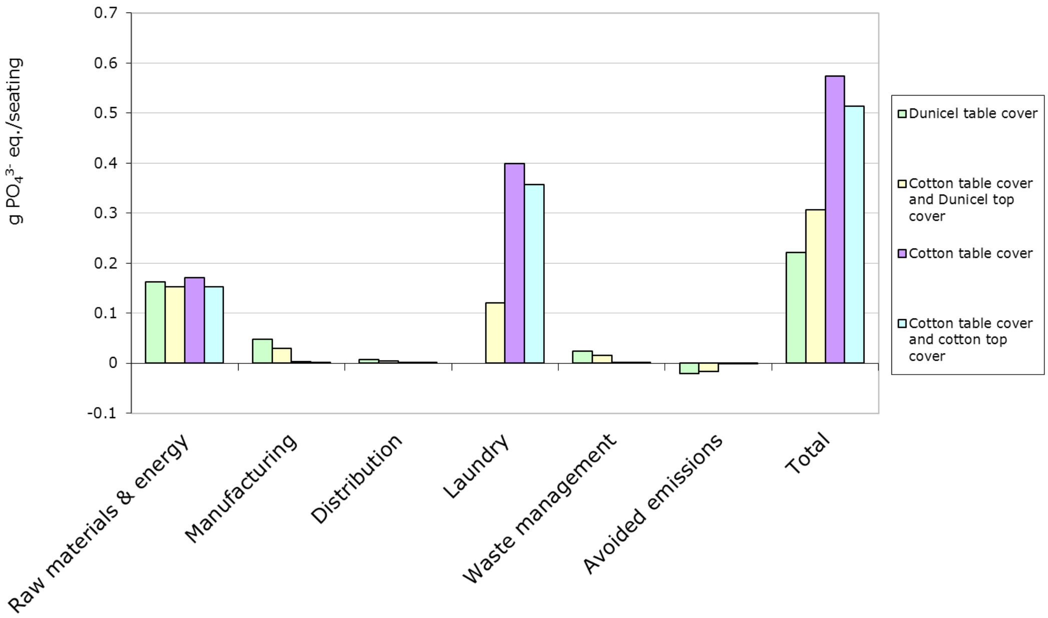

Figure 5 Eutrophication potential for the four table cover systems on the German market (unit: g PO_4^{3-} e/seating).

For the Dunicel table/top cover, the production of raw material and energy is very dominant in terms of eutrophication. 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 global warming.

For reusable table covers, the laundry is the life cycle phase that emits the highest amount of eutrophying substances. 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. The production of raw materials and energy are also important for the reusable table covers.

3.2. Results, Sweden

3.2.1. All impact categories, compared to Dunicel table cover

The results for all table cover systems on the Swedish market are presented in Figure 6. The results are presented as relative to the Dunicel table cover, i.e. the result of Dunicel table cover has been set to 100% in each impact category. Please note that the figure does not imply the relative importance of different impact categories.

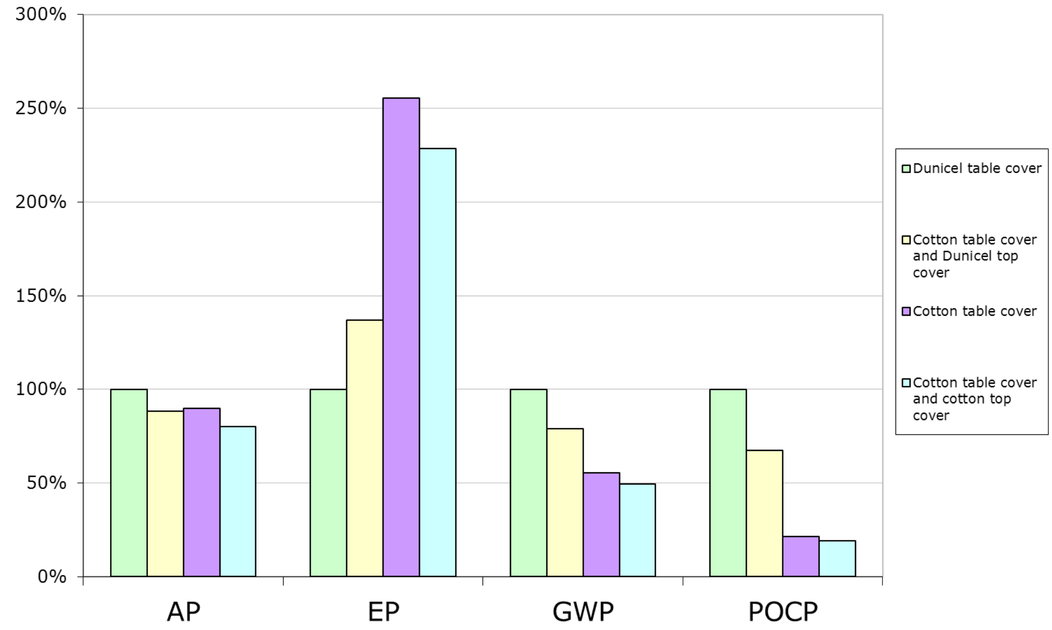

Figure 6 Environmental impact of the four table cover systems on the Swedish market compared to the Dunicel option. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the four studied table cover systems are relatively equal with regard to AP (acidification potential) on the Swedish market. For eutrophication (EP) the two systems with single-use table covers cause less impact than the systems using only cotton table covers, while for global warming (GWP) and photochemical oxidant creation potential (POCP), the relation is the opposite with the systems using cotton table covers causing half or a quarter of the impact of the single-use table cover system.

3.2.2. Selected impact categories, per life cycle phase

This section presents the same results as before, but divided into the six life cycle phases as defined in Section A.3. The results for the Swedish market are presented for global warming in Figure 7.

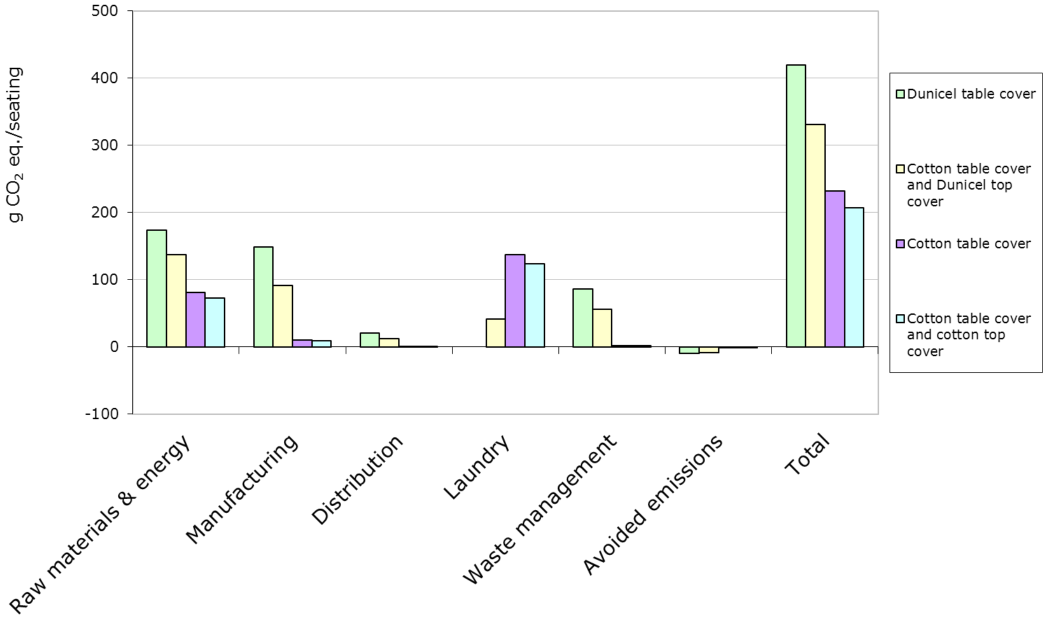

Figure 7 Global warming potential for the four table cover systems on the Swedish market (unit: g CO_2e/seating).

As the results show when divided per life cycle phase, the emissions of greenhouse gases for the Dunicel table cover mainly come from the production of raw materials and energy and from the manufacturing of the table cover. For the system using a cotton table cover in combination with a Dunicel top cover, the emissions of greenhouse gases is less than for the Dunicel table cover option, since the reduced amount of material used saves more emissions than is generated by the laundry process for the cotton table cover.

For the two systems with reusable cotton table/top covers, the main emission of greenhouse gases comes from the laundry followed by emissions from the production of raw materials and energy. The emissions from the laundry are caused by the use of natural gas and electricity at the laundry facility. The "avoided emissions" are not significant for table covers on the Swedish market, as it was assumed than the electricity generated during incineration replaced a Swedish electricity mix.

The contribution of the distribution transport is small for all table covers compared to the other life cycle phases.

To contrast these results, the results for eutrophication (EP) are plotted in Figure 8. The eutrophication impact category might be quite different from global warming, as it is not as dependent on what type of electricity is used as global warming.

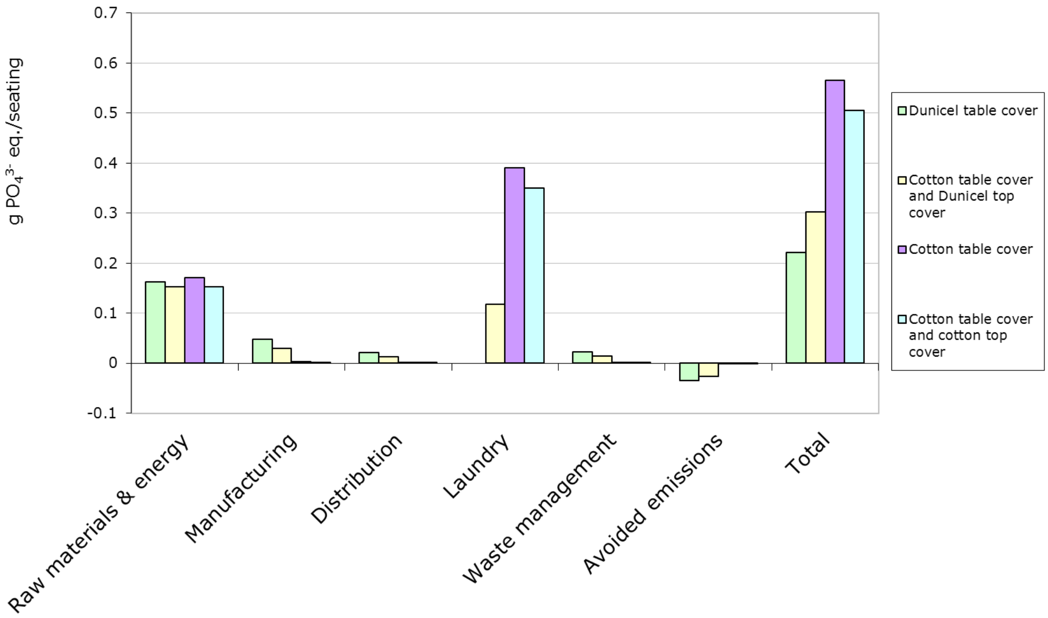

Figure 8 Eutrophication potential for the four table cover systems on the Swedish market (unit: g PO_4^{3-} e/seating).

For the Dunicel table/top cover, the production of raw material and energy is very dominant in terms of eutrophication. 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 global warming.

For reusable table covers, the laundry is the life cycle phase that emits the highest amount of eutrophying substances. 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. The production of raw materials and energy are also important for the reusable table covers.

3.3. Results, United Kingdom

3.3.1. All impact categories, compared to Dunicel table cover

The results for all table cover systems on the British market are presented in Figure 9. The results are presented as relative to the Dunicel table cover, i.e. the result of Dunicel table cover has been set to 100% in each impact category. Please note that the figure does not imply the relative importance of different impact categories.

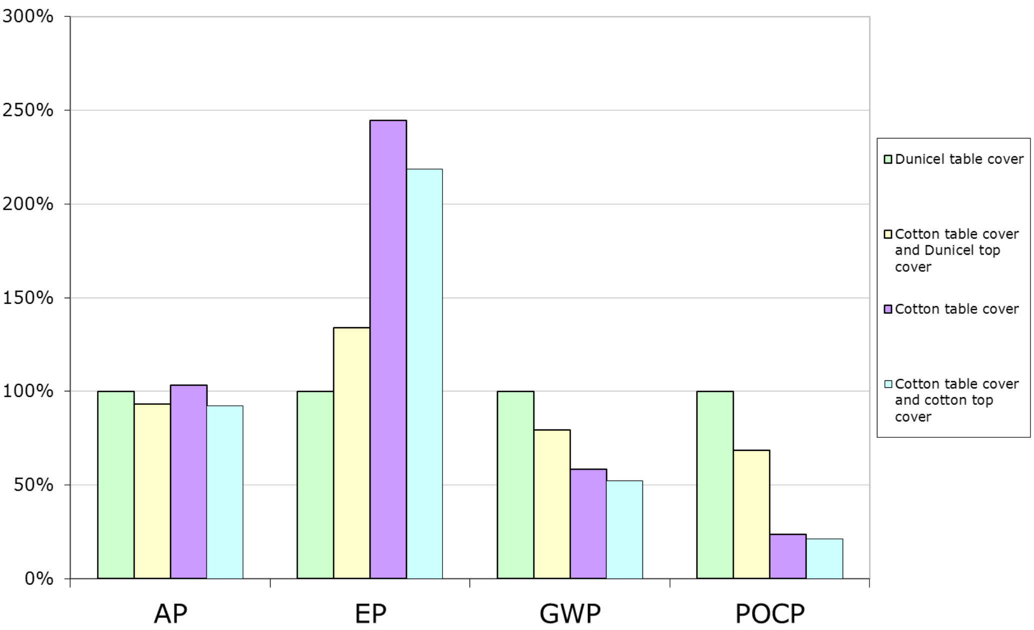

Figure 9 Environmental impact for the four table cover systems on the British market compared to the Dunicel option. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the four studied table cover systems are relatively equal with regard to acidification (AP) on the British market. For eutrophication (EP)) the two systems with single-use table covers cause less impact than the systems using only cotton table covers, while for global warming (GWP) and photochemical oxidant creation (POCP), the relation is the opposite with the systems using cotton table covers causing half or a quarter of the impact of the single-use table cover system.

3.3.2. Selected impact categories, per life cycle phase

This section presents the same results as before, but divided into the six life cycle phases as defined in Section A.3. The results for the British market are presented for global warming in Figure 10.

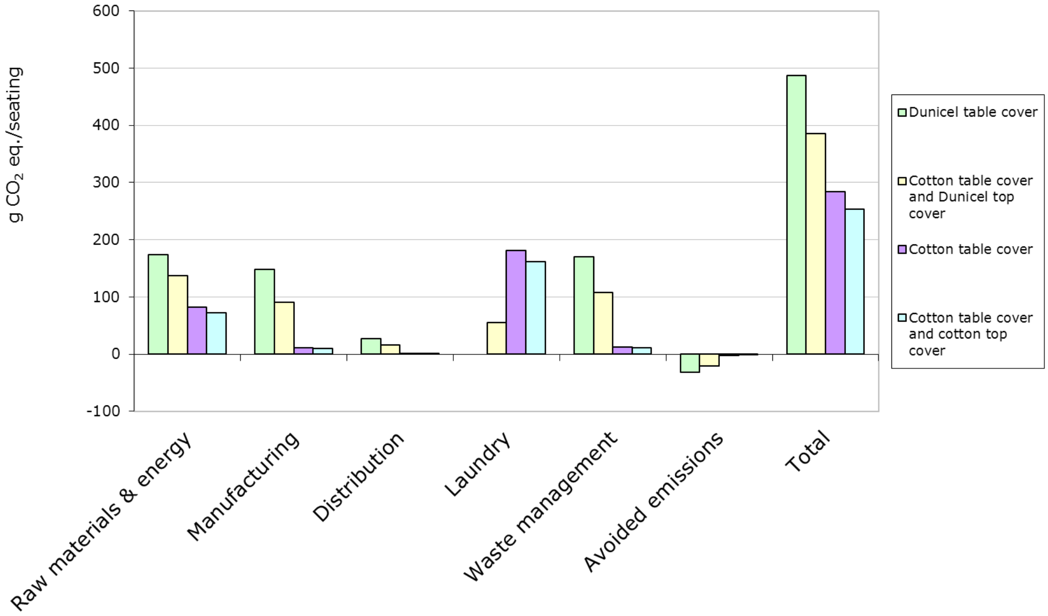

Figure 10 Global warming potential for the four table cover systems on the British market (unit: g CO_2e/seating).

As the results show when divided per life cycle phase, the emissions of greenhouse gases for the Dunicel table cover mainly come from the production of raw materials and energy and from the manufacturing of the table cover. For the system using a cotton table cover in combination with a Dunicel top cover, the emissions of greenhouse gases is less than for the Dunicel table cover option, since the reduced amount of material used saves more emissions than is generated by the laundry process for the cotton table cover. Waste management is also significant for the Dunicel table covers on the British market due to the emissions of methane at landfill. In the UK, much more waste is disposed of at landfill compared to Germany and Sweden (instead of being incinerated).

For the two systems with reusable cotton table/top covers, the main emission of greenhouse gases comes from the laundry followed by emissions from the production of raw materials and energy. The emissions from the laundry are caused by the use of natural gas and electricity at the laundry facility.

The contribution of the distribution transport is small for all table covers compared to the other life cycle phases.

To contrast these results, the results for eutrophication (EP) are plotted in Figure 11. The eutrophication impact category might be quite different from global warming, as it is not as dependent on what type of electricity is used as global warming.

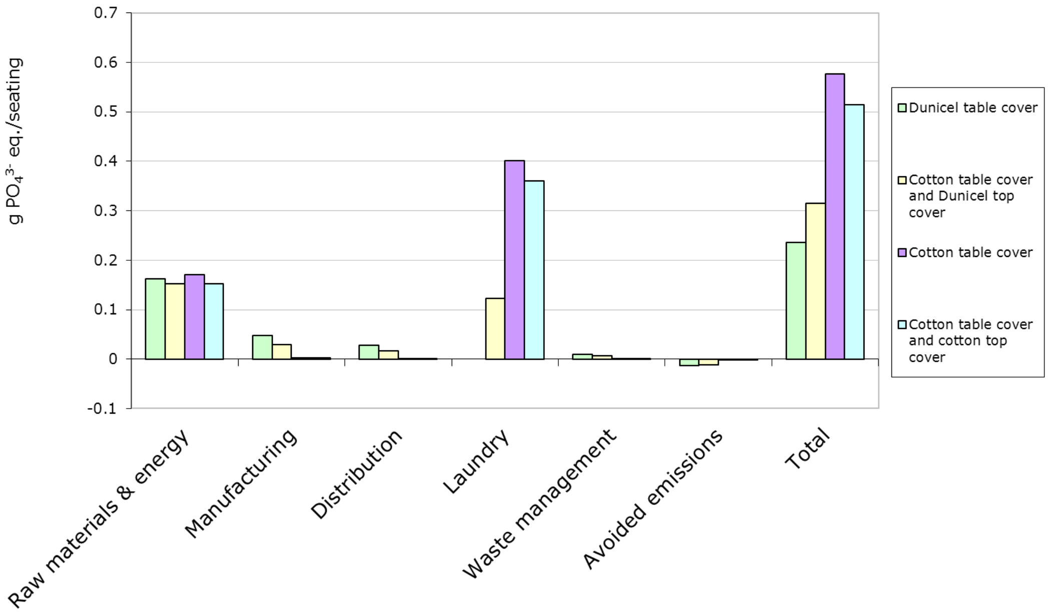

Figure 11 Eutrophication potential for the four table cover systems on the British market (unit: g PO_4^{3-} e/seating).

For the Dunicel table/top cover, the production of raw material and energy is very dominant in terms of eutrophication. 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 global warming.

For reusable table covers, the laundry is the life cycle phase that emits the highest amount of eutrophying substances. 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. The production of raw materials and energy are also important for the reusable table covers.

4. Discussion

In this study, the environmental impact of different table cover options from a life cycle perspective has been calculated and analysed. The results were analysed and interpreted using sensitivity analysis, dominance analysis, completeness check and consistency check in 0.

When interpreting the results, the goal and scope should always be considered. In this case the goal was to calculate and compare the environmental impact of four table/top covers. The study thus answers the question "what environmental impact may be attributed to the use of a table cover?"

In order for the attributed impact of different table covers to be comparable, they must have consistent system boundaries and methodologies. The general practices of the International EPD System have been followed. A potential problem with this may be that the Duni table covers 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 phases as well, such as the laundry facility.

The sensitivity analyses that have been performed show that there are potentially large uncertainties in the results for the reusable table covers depending on the number of seatings that a table cover is used during its lifetime but also depending on energy consumption for the laundry service. Further, the sensitivity analyses showed that the results for the single-use table covers are less sensitive to changes in the input data than the reusable table covers.

The completeness check also showed that a majority of the data gaps identified in section A.7.7 may influence the conclusions of the study. Most of these data gaps concern the reusable table covers. As the stud has been commissioned by Duni, it is preferable that the single-use systems are as complete as possible, thus reflecting the single-use systems as correct as possible. This has been assessed as being accomplished in this study. Though, for the reusable systems, there are data gaps that can be filled, thereby reducing the uncertainty of the results which would benefit the comparison between the single-use and reusable systems.

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 "providing table cover for one seating at an average restaurant" at each market was used: The underlying assumption is that the material type and table cover size do not make any difference for providing this function.

The study covers four environmental impact categories used in the International EPD System. Though representing a diverse set of environmental impacts, covering many relevant emissions and giving different results, they are not a comprehensive set. Some environmental impacts that are not covered by these impact categories are toxicity (human and ecological), water scarcity, stratospheric ozone depletion, loss of biodiversity and land use. 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 in the future.

Another aspect to keep in mind when interpreting the results is what activities and related emissions are in the control of Duni. The total results differ between the three markets, and in some cases the relative performance is different as well. These differences are 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 better waste management system (from a systems perspective).

5. Conclusions, limitations and recommendations

The study has calculated and presented the environmental impact that can be attributed to the use of four different table cover options from a life cycle perspective. The study has considered potential environmental impacts in terms of global warming, acidification, eutrophication, and photochemical oxidant creation. Based on the study results, these are the main conclusions:

- There is not a simple answer to the question *which table cover option has the lowest environmental impact?* The result of the comparison depends on the market and which environmental impact category is judged to be most urgent to address.
- For global warming, which currently is a prominent issue in the environmental debate, the most favourable option appears to be the options using cotton table covers. This is true on the Swedish and British market, while the difference between the options is smaller in Germany. Though, the results are sensitive for changes in number of seating and type of electricity used during laundry. For eutrophication, the single-use table cover options appear to be the favourable option on all three markets.
- Using a smaller table top in combination with a table cover that is washed less frequently appears to have mostly positive effects, with the exception of eutrophication potential, which increases with the use of cotton products.
- The three markets show almost the same result in terms of comparison between the options. The main exception is global warming potential on the German market, where the difference between the options is quite small compared to the other markets.
- The sensitivity analysis has shown that there can be large differences in environmental performance for the cotton table/top covers depending on how many seating that they are used but also depending on the amount and type of energy that is used during laundry. An important aspect to reduce the environmental impact of table covers is thus to increase the number of seatings (if possible for hygienic or other reasons).
- Recycling of tissue appears to be beneficial for the single-use table/top covers with regard to acidification, eutrophication and photochemical ozone creation potential, while for Global warming potential recycling may cause increased emissions of CO_2 when recycling is performed on the German market. If recycling instead takes place on the Swedish market, it is likely that the increase in GWP is smaller compared to the German market or that the GWP is equal to the base case due to less emissions of CO_2 per kWh when using Swedish country-average supply mix of electricity.
- Data gaps have been identified. The data gaps all contribute to underestimating the environmental impact of the four studied product systems. POCP appear to be the impact category that is affected the most by these data gaps, but AP, EP and GWP are also influenced. The data gap´s impact on the conclusions has been assessed in the completeness check and the results show that a majority of these data gaps may influence the conclusions. As the majority of these data gaps affect the reusable table covers, the results for the reusable table covers are to be considered more uncertain than those of the single use table covers.

- The study is limited to four environmental impact categories: global warming, acidification, eutrophication and photochemical oxidant creation. To give a more comprehensive view of impacts caused by cotton production, toxicity (human and ecological) as well as water use should preferably also be included. 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 table covers:

- Use the information on the most contributing life cycle phases as a basis for further environmental improvement of the environmental performance in the supply chain. 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 verified environmental product declarations (EPDs) in an internationally-accepted system to communicate reliable environmental information to customers and stakeholders. There is currently work going on to create product category rules (PCR) for tissue products, which could be applied to Dunicel table covers.

- Consider including additional environmental impact categories, such as toxicity and water use in future environmental life-cycle studies. This would, however, require extra work in terms of data collection and methodology choice as this would require 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 D.

Appendix A Detailed methodology

This appendix provides an in-depth description of the goal, scope and life cycle inventory analysis used in the life cycle assessment (LCA) of table covers. The intended audience is LCA experts and stakeholders interested in the methodology of this study.

A.1 Goal

The goal of this study is to calculate and compare the environmental impact of the table cover options listed in Table 1. The Dunicel table cover is based on data from Duni and an life cycle assessment of Duni table table/top covers (EG, personal communication; Jelse & Westerdahl, 2010). The cotton table covers and top covers are assumed to be used for several seatings before being washed. The life time of a cotton product was assumed to be 40 wash cycles. All products are modelled as white and without print.

Table 1: The table cover options investigated in this study.

	Number of seatings	Size (cm x cm)	Grammage (g/m2)	Weight (g)
Dunicel table cover	1	130x130	135	228
Cotton table cover	1.5	130x130	220	372
Cotton table cover & Dunicel top cover	5 (table cover), 1 (top cover)	130x130 100x100	220 135	372 135
Cotton table cover & cotton top cover	5 (table cover), 1.5 (top cover)	130x130 100x100	220 220	372 220

The study is an attributional LCA (in contrast to a consequential LCA) that answers the question "what environmental impact can be attributed to the use of a table cover option?" Another type of question that could be asked is "what would be the environmental consequences of one additional use of a table cover option (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. 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 are primarily intended for internal use to increase knowledge about the environmental impact of Dunicel table covers and the difference in performance between single-use and reusable products. The modelling of the Duni products 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 options, a fair functional unit must be used as a basis of comparison. In this study, the functional unit was chosen as "providing table cover for one seating at an average restaurant" at three markets selected by Duni: Germany, Sweden and the United Kingdom. It was assumed that the difference in material and size of the different products made no difference in providing this function for the final consumer.

A.3 System boundaries

The system boundary has been chosen to cover all processes relevant for the comparison of table cover options using both single-use and reusable products. When dividing unit process into life cycle phases, care has been taken to use similar system boundaries as is general practice 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. This information has been added as additional information to make the single-use and reusable products systems more easily comparable, the main scope of the study is however still cradle to gate.

The study covers the entire life cycle of the products, from forestry or cultivation of cotton 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 A.7.6.3.

The study covers products 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 C.3.

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. 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 phases (see Figure 12 and Figure 13):

- **Raw materials & energy**. For Dunicel, 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 cotton products this includes cotton cultivation, fibre processing and yarn processing.

- **Manufacturing**. For Dunicel, this includes transports of raw materials, chemicals and fuels to paper production, tissue paper production and converting. For cotton products, this corresponds to the weaving process.
- **Distribution**. This is the transport from converting or weaving to an average restaurant at each market.
- **Laundry**. For reusable table/top covers, this life cycle phase corresponds to the transportation of to and from an external laundry facility and the use of electricity and steam for washing the table covers. It also includes emissions from waste water treatment, and emissions of eutrophying substances to water. This life cycle phase is not relevant for single-use products.
- **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 according to the polluter-pays principle (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 phase "avoided emissions" is generally not included in the International EPD System. In order to use the results in an EPD, the life cycle phase avoided emissions should therefore be removed. In an EPD, the system boundaries are 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 boundaries and life cycle phases for single-use and reusable products are presented in Figure 12 and Figure 13.

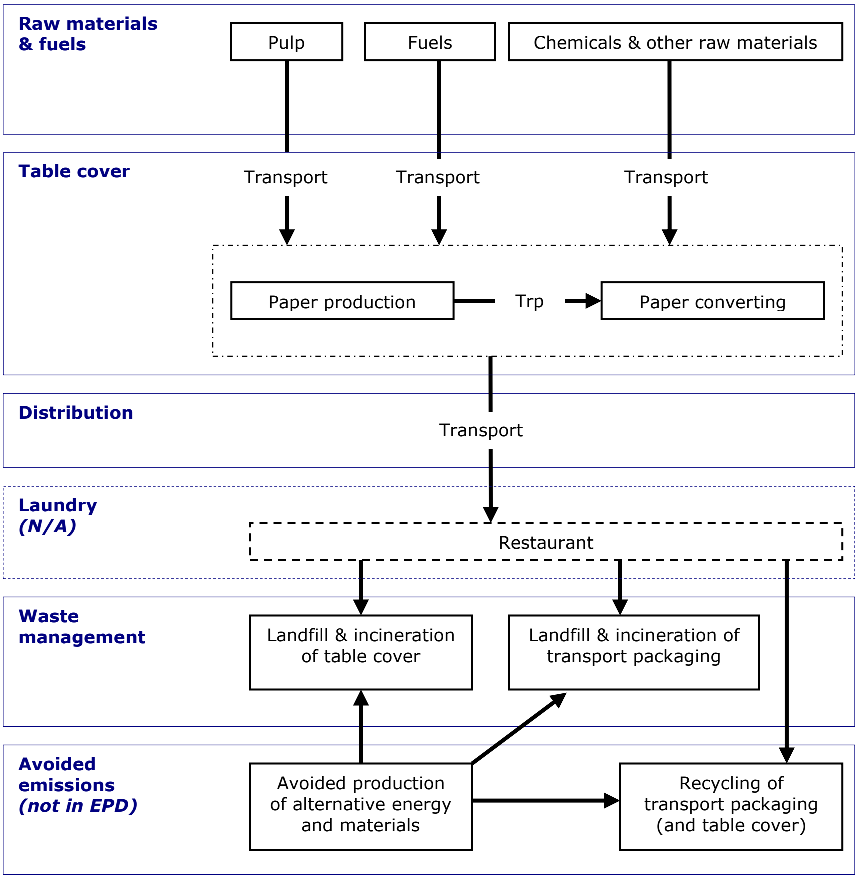

Figure 12 System boundaries and cycle phases for the single-use table and top cover – Dunicel.

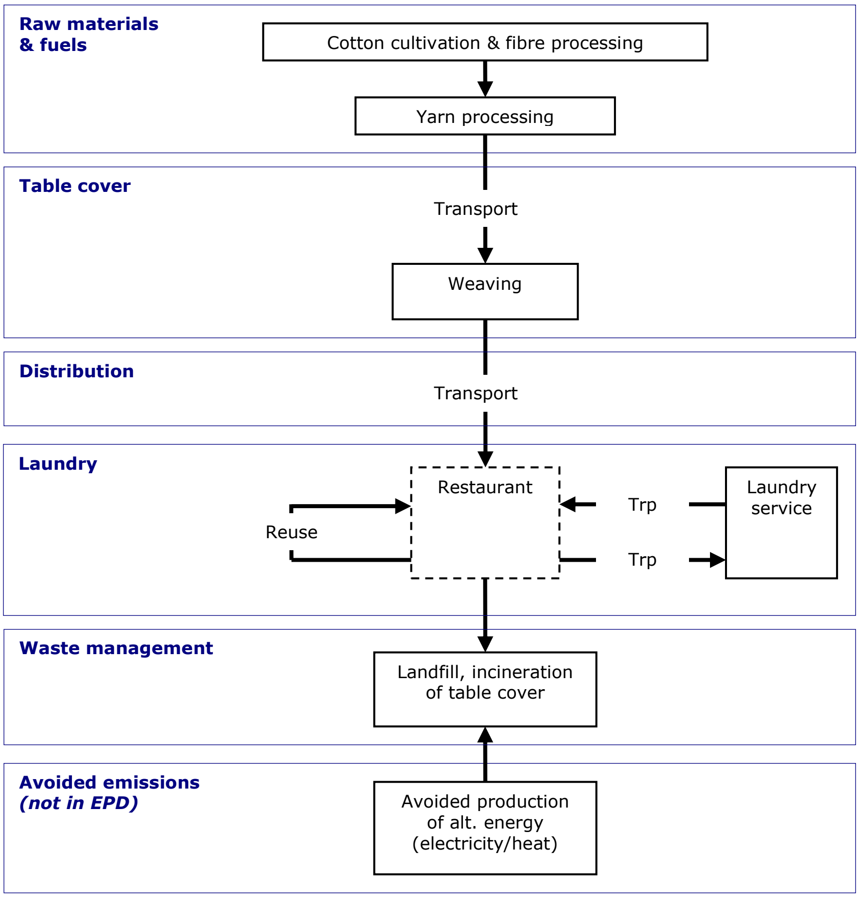

Figure 13 System boundaries and life cycle phases for the reusable products: cotton table/top cover.

The largest difference between reusable and single-use products is the inclusion of the laundry service and reuse for cotton products. The reusable products were assumed to be used during either 1.5 or 5 seatings before washing and they were assumed to be washed 40 times during its life cycle. The material attributed to one use of a reusable table cover is therefore between 1/200 and 1/60 depending on the number of times it is used between each wash. After being used 40 times, the textile table covers were assumed to be collected together with the mixed municipal solid waste at each market.

A.4 Impact assessment categories

The potential environmental impact of the systems is calculated in four separate categories: climate change, acidification, eutrophication and photochemical oxidant creation; see Table 2. Characterisation factors from the International EPD system were used to convert emissions from the life cycle to these impact categories (SEMCo, 2008b[2]).

[2] Original references: IPCC, 2001; CML, 1999; Huijbregts, 1999; Jenkin & Hayman, 1999; Derwent et al., 1998; Heijungs et al., 1992.

Table 2 Environmental impact assessment categories used in this study.

Impact category	Characterisation factor (SEMCo, 2008b)	Unit[3]
Climate change	GWP, 100 years	g CO_2 equivalents
Acidification	AP	g SO_2 equivalents
Eutrophication	EP	g PO_4^{3-} equivalents
Photochemical ozone formation	POCP	g C_2H_4 equivalents

In the assessment of acidification potential, it should be noted that only emissions of ammonia, nitrogen dioxide, nitrogen oxides, sulphur dioxide and sulphur oxides have been included in the characterisation factor (SEMCo, 2008b). Emissions of other substances that can have an acidifying effect, such as acids, are not included. In addition to the environmental impact categories listed above, primary energy use is also calculated and presented.

Impacts such as land use, human toxicity, ecotoxicity and impact of water use have not been included.

The aggregation of impact categories into a single score – "weighting" – has not been performed as this 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 on the professional market in each of the three countries. 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 A.7.7)
- Dunicel is based on the actual supply chain of Duni, while the reusable products are based on estimated alternative products. The area for which this might have the largest impact is the electricity mix that is used.

This version of the report has not been critically reviewed by a panel of interested parties, why no comparative assertion should be made to the public regarding the relative environmental performance of the different systems according to the standard (ISO, 2006).

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

A.6 Interpretation methods

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

A.6.1 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 seatings for reusable products**. In the base case, it was assumed that the reusable top cover and table cover were used 1.5 or 5 times respectively before each wash and that they were washed 40 times before being replaced. In this sensitivity analysis, two scenarios were developed. In the first scenario, it was assumed that the reusable products were only washed 20 times during its entire life and the number of uses between each wash was assumed to be lower than in the base case, see Table 3. In the second scenario, the reusable products were instead assumed to be washed 60 times and the number of uses between each wash was higher than in the base case, see Table 3.

Table 3 Number of seatings between washes for the table cover and top cover for the base case and for the scenarios with a low and high number of seatings.

Table cover options	Number of seatings between washes: table cover			Number of seatings between washes: top cover		
	Base case	Low	High	Base case	Low	High
Dunicel table cover	1	1	1	N/A	N/A	N/A
Cotton table cover and Dunicel top cover	5	2.5	7.5	1	1	1
Cotton table cover	1.5	1	2	N/A	N/A	N/A
Cotton table cover and cotton top cover	5	2.5	7.5	1.5	1	2

- **Energy use at laundry.** In the base case, a country-average supply mix of electricity was used at laundry service. In this sensitivity analysis, a low emission scenario and a high emission scenario was developed. In the low emissions scenario, less energy was assumed to be used in the laundry compared to the base case and electricity produced from renewable energy sources was used. In the high emission scenario, more energy was assumed to be used compared to the base case and heat was assumed to be generated from diesel instead of using natural gas.
- **Recycling of Dunicel.** In the base case, there is no recycling of the Dunicel material. In this sensitivity analysis, it is instead assumed that all the Dunicel material is sent for recycling.
- **Low-carbon electricity at Bramsche manufacturing site.** In the base case, a German supply mix of electricity is used for the converting facility in Bramsche. In this sensitivity analysis, electricity from hydropower was instead used and compared to the base case.

A.6.2 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.6.3 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.6.4 Dominance analysis

The dominance analysis should analyse the results to answer the question: *what life cycle phase(s) is (are) the most dominant contributor to the total results*? Each product system and environmental impact category is analysed and discussed separately.

A.7 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 use adjusted site-specific data for paper production and paper converting, while data from literature and databases were used for alternative products.

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

A.7.1 Product specifications and transport packaging

The Dunicel table/top covers are based on existing products, where product specifications were provided by Duni (EG, personal communication). The reusable products are estimates based on size and grammage.

Dunicel is a product that contains tissue paper, 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 products are listed in Table 4. Data on transport packaging for single-use products were provided by Duni (HJS, personal communication). No information was available on the amount of transport packaging for reusable products, why it was assumed that they had no transport packaging. This is very likely an underestimate of actual conditions.

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

	Corrugated cardboard (g/product)		Polypropylene film (g/product)	
	Single use	Reusable	Single use	Reusable
Dunicel table cover	14.5 g	N/A	6 g	N/A
Cotton table cover and Dunicel top cover	14.5 g	-	6 g	-
Cotton table cover	N/A	-	N/A	-
Cotton table cover and cotton top cover	N/A	-	N/A	-

A.7.2 Dunicel

This section provides information on the LCI of the Duni table/top cover. For a list of data gaps, see Section A.7.6.3.

A.7.2.1 Pulp production

Pulp for tissue paper is purchased from various suppliers. Data from 2009 from Jelse & Westerdahl (2010) was used, where the main suppliers provided specific data on pulp production, and other data was approximated with pulp production data from PE International (2006).

A.7.2.2 Paper production

The production of tissue paper takes place in Sweden, and data from Jelse & Westerdahl (2010) was used corresponding to the year 2009. The data covered raw materials, chemicals (used for cleaning, waste water treatment, etc.), 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.

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 A.7.6.3.

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).

A.7.2.3 Converting

Converting of tissue paper into table/top covers takes place in Bramsche (Germany) for all Duni products in this study. Data for the converting site for 2009 was used from Jelse & Westerdahl (2010). The data corresponded to converting of Dunicel table/top covers. It was assumed that the same data could be used, assuming the same energy consumption, etc., per square metre as for the table/top covers.

The electricity mix purchased in Bramsche consists of fossil energy, but also 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 A.7.4).

A.7.3 Cotton products

This section provides information on the LCI of cotton table/top covers. The same data as in Jelse & Westerdahl (2010) was used.

A.7.3.1 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).

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)

A.7.3.2 Weaving of cotton

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 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 fabric 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 fabric has been used as it appears to be a conservative estimate.

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

A.7.3.3 Laundry service

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

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 maximum criteria allowed 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.

A.7.4 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:

- **China**: mainly power from coal, but also some hydro power.
- **Germany**: more than half of the electricity supply from fossil resources (coal and natural gas), but also a large share of nuclear power and a larger share of wind power than in other countries.
- **Sweden**: mainly nuclear power and hydro power, but some imports of hydro power and power from fossil resources from neighbouring countries.
- **United Kingdom**: mainly coal, natural gas and nuclear power. Some imports of mainly nuclear power from neighbouring countries.
- **United States**: mainly coal, but also important shares of natural gas and nuclear power.

In addition to this, an average EU-25 electricity mix was used when the European country in which a process takes place was unknown. The most important example of this is weaving of cotton.

A.7.5 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.

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 products 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 distances from the distribution centre to a customer, data from Jelse & Westerdahl (2010) was used.

Distribution of cotton table/top covers was assumed to take place by truck (1000 km) for all three markets.

A.7.6 Waste management and avoided emissions

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

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 Arena et al (2003) and landfill of organic material, which is described in detail in Section A.7.6.2

A.7.6.1 Waste management scenarios

The waste management scenarios for Dunicel and cotton products are shown in Table 5. It was assumed that all products 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 at the three markets.

	Landfill	Incineration
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%)	–

A.7.6.2 Methane emissions at landfill

When organic material such as paper or cotton 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, a dry weight of 90% and a cellulose content of 50% were assumed. For cotton products, a cellulose content of 77% of dry weight was assumed for cotton based on Reddy and Yang (2005). The dry weight was assumed to be 90% of the total weight of the product.

A.7.6.3 Avoided emissions

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
- **Corrugated cardboard**: linerboard from virgin raw materials

A.7.7 Known data gaps

The following data gaps are known to exist in the LCI. This lack of data is analysed in Section C.2.

Product specifications and transport packaging:

- Transport packaging for reusable products

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 Dunicel converting:

- Chemicals for tissue paper production: about 14 g/kg Dunicel.
- Chemicals for converting: about 17 g/kg Dunicel.

Cotton cultivation and processing of fibre and yarn:

- *No known data gaps.*

Weaving of cotton:

- 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 table/top covers to restaurant.

Waste management:

- *No known data gaps.*

A.7.8 Allocation

For the production of cotton, allocation was based on economic allocation between cotton seed and cotton fibres (Nemecek & Kägi, 2007). For the flax production, allocation between the main product and the co-products were performed on an economic basis.

For paper production, allocation 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 paper converting, mass allocation was used for most parameters such as emissions to water, waste and chemicals. 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. Data on electricity and natural gas use were provided per product type.

For the laundry service, the electricity and water use were allocated per kilogramme of washed laundry.

A.7.9 Selected results from the Life Cycle Inventory

Table 8 presents the results for primary energy demand (renewable and non-renewable) for the table cover options on each of the three markets. For each market, the primary energy demand has been split into two categories; primary energy demand from cradle to waste management and primary energy demand from avoided emissions, where the net amount of primary energy is the sum of both categories. For the avoided emissions, the primary energy demand is negative since energy is saved by recycling materials and/or recovering heat and electricity from for example incineration.

Table 8 Total primary energy demand (as gross calorific value) for the four table cover options (unit: MJ/seating). Numbers have been rounded to two valid digits.

Table cover options	**Germany**		**Sweden**		**United Kingdom**	
	Cradle to waste management	Avoided emissions	Cradle to waste management	Avoided emissions	Cradle to waste management	Avoided emissions
Dunicel table cover	8.6	-2.0	8.9	-0.44	9.2	-0.66
Cotton table cover and Dunicel top cover	6.8	-1.3	6.9	-0.33	7.1	-0.46
Cotton table cover	4.9	-0.092	4.6	-0.015	4.8	-0.038
Cotton table cover and cotton top cover	4.3	-0.082	4.1	-0.013	4.3	-0.034

Appendix B Additional characterisation results

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

B.1 Additional results, Germany

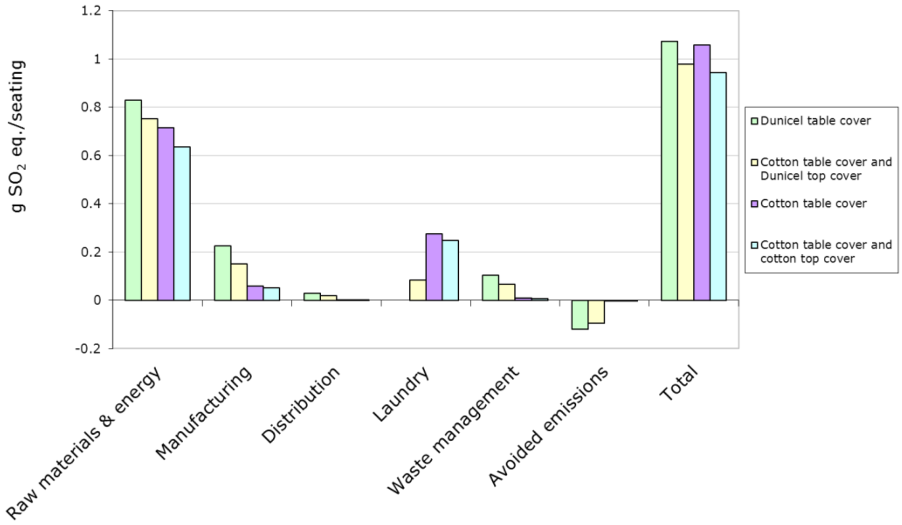

Figure 14 Acidification potential for the four table cover systems on the German market (unit: g SO_2e/seating).

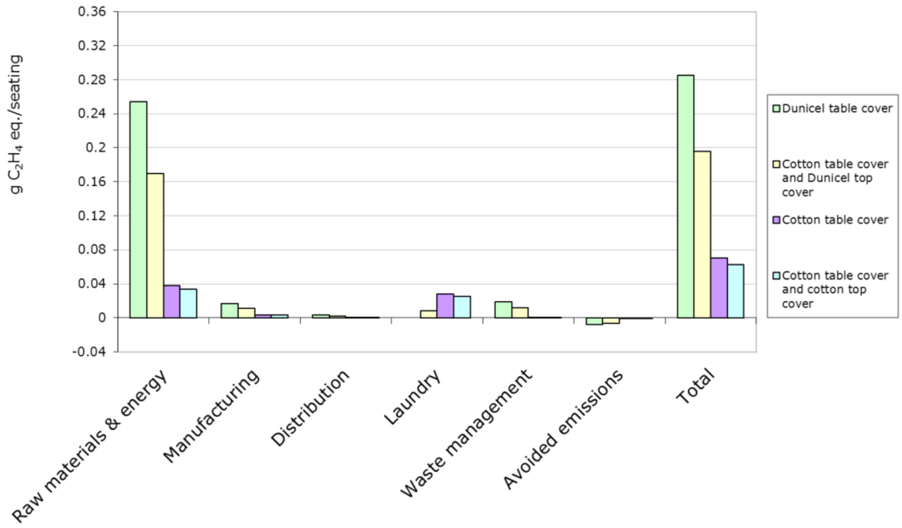

Figure 15 Photochemical oxidant creation potential for the four table cover systems on the German market (unit: g C_2H_4e/seating).

B.2 Additional results, Sweden

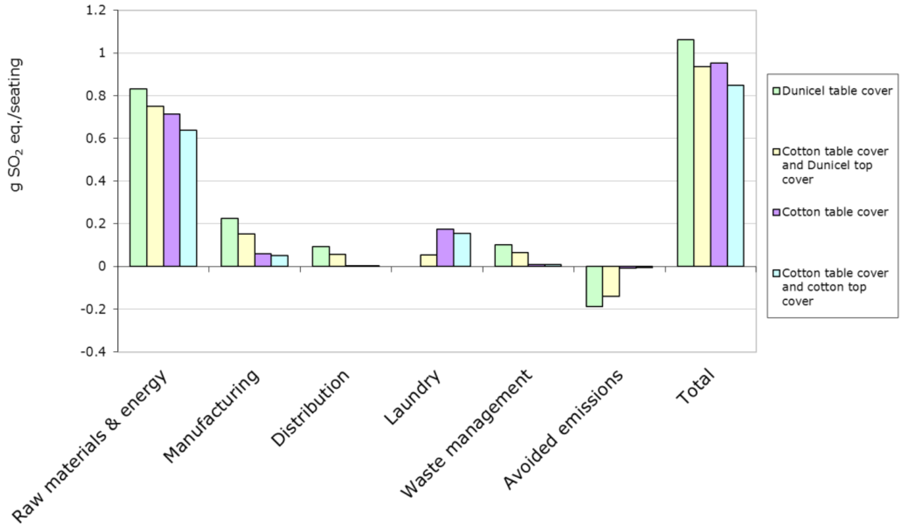

Figure 16 Acidification potential for the four table cover systems on the Swedish market (unit: g SO_2e/seating).

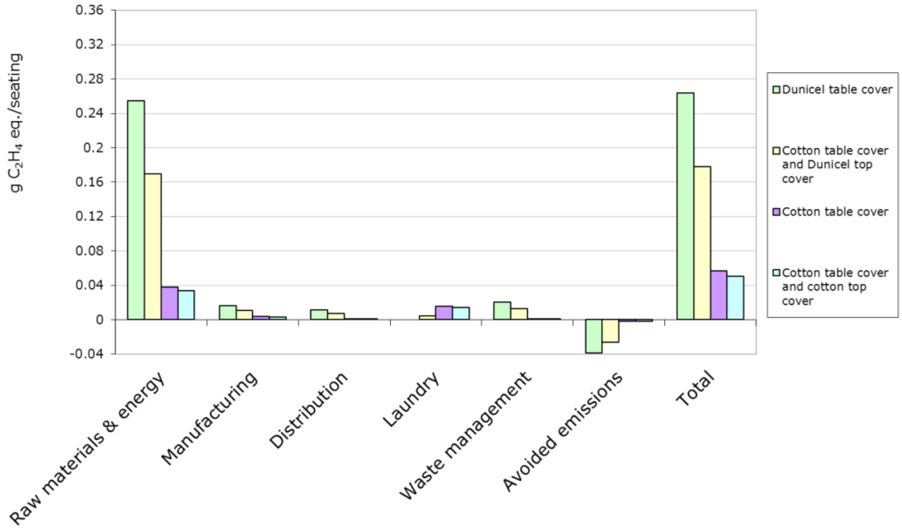

Figure 17 Photochemical oxidant creation potential for the four table cover systems on the Swedish market (unit: g C_2H_4e/seating).

B.3 Additional results, United Kingdom

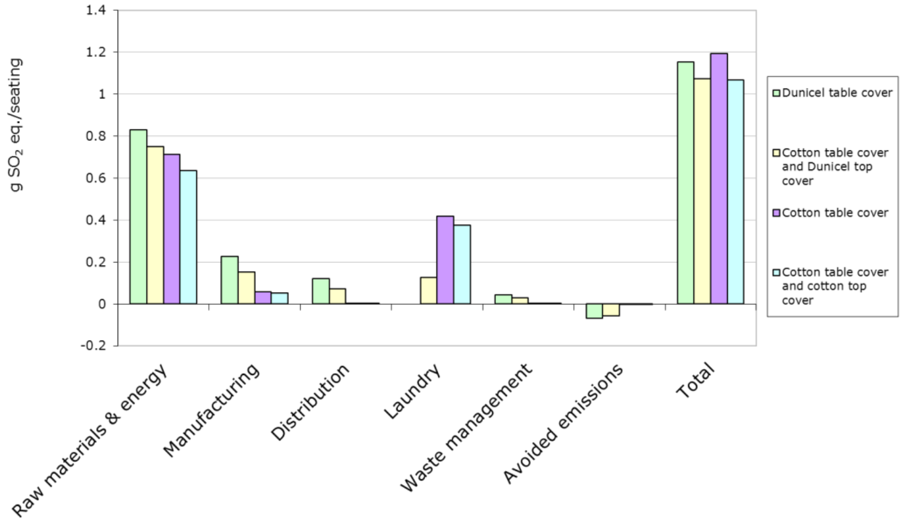

Figure 18 Acidification potential for the four table cover systems on the British market (unit: g SO_2e/seating).

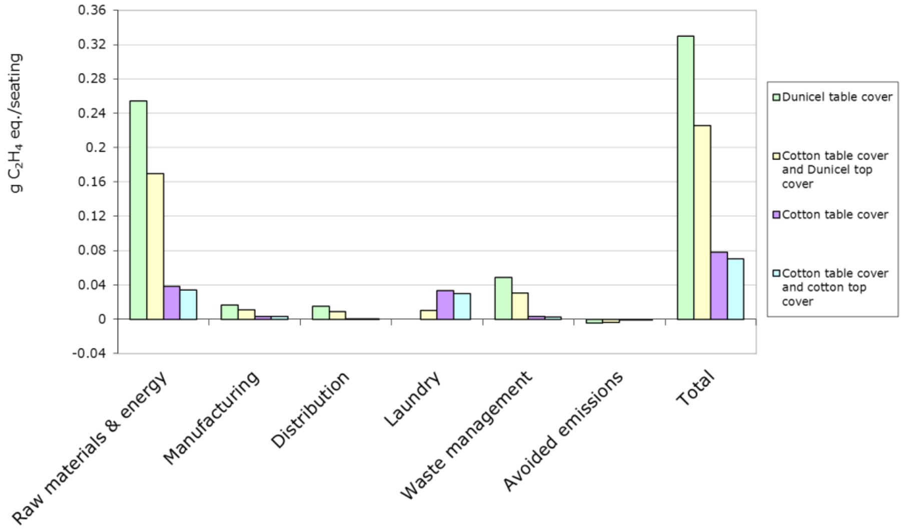

Figure 19 Photochemical oxidant creation potential for the four table cover systems on the British market (unit: g C_2H_4e/seating).

Appendix C Detailed interpretation

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

C.1 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.

C.1.1 Number of seatings

In this sensitivity analysis, the number of seatings that the reusable products go through during its life time is analysed. In the base case, it was assumed that the cotton table/top covers were used 5 or 1.5 times and that they were washed 40 times before being replaced. In this sensitivity analysis, two scenarios were developed. In the first scenario, it was assumed that the reusable products were only washed 20 times during its entire life and the number of uses between each wash was assumed to be lower than in the base case, see **Table 3**. In the second scenario, the reusable products were instead assumed to be washed 60 times and the number of uses between each wash was higher than in the base case, see **Table 3**.

Table 9 Number of seatings between washes for the table cover and top cover for the base case and for the scenarios with a low and high number of seatings.

Table cover options	**Number of seatings between washes: table cover**			**Number of seatings between washes: top cover**		
	Base case	Low	High	Base case	Low	High
Dunicel table cover	1	1	1	N/A	N/A	N/A
Cotton table cover and Dunicel top cover	5	2.5	7.5	1	1	1
Cotton table cover	1.5	1	2	N/A	N/A	N/A
Cotton table cover and cotton top cover	5	2.5	7.5	1.5	1	2

The normalized results for all impact categories are presented in Figure 20.

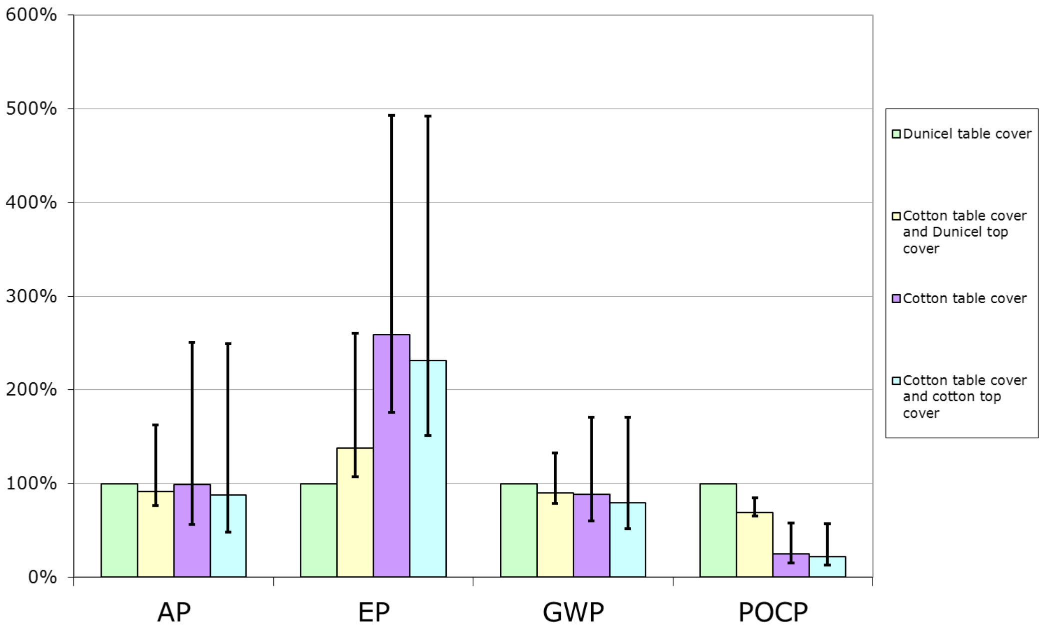

Figure 20 Sensitivity analysis of the importance of the assumed number of seatings for the reusable products on the German market. The coloured bar represents the base case, the top end of the error bars represents the scenario with low number of seatings while the lower end of the error bars represents the scenario with high number of seatings. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the number of seatings has a large effect on the environmental performance of the reusable products. The two scenarios used here have been selected to represent likely minimum and maximum number of seatings for a top/table cover used at a restaurant, based on number of uses between washes and number of wash cycles during the products lifetime. The environmental impact of the systems using only reusable top/table covers are more sensitive to changes in number of seatings than the system with a reusable table cover and a single use top cover.

If the reusable products are only used for a low number of seatings, they have a larger environmental impact for three of the impact categories (AP, EP and GWP) compared to the single use table covers. With regards to eutrophication potential, the reusable table covers have a higher impact than the reusable table covers for both scenarios with high and low number of seatings. For photochemical oxygen creation potential, the opposite can be seen where the reusable table covers have a smaller environmental impact than the single use table covers.

C.1.2 Energy use at laundry service

In the base case, it was assumed that the electricity and heat consumption during laundry was 0.3 and 2 kWh/kg laundry respectively. A country-average supply mix of electricity was used at laundry service at each market and the heat was obtained from steam produced from natural gas.

In this sensitivity analysis, two scenarios was created; one low emission scenario and one high emission scenario. In the low emission scenario, the electricity and heat consumption was set to 0.2

and 1 kWh/kg laundry respectively, and the electricity was assumed to be produced from renewable energy sources and the heat from natural gas. In the high emission scenario, the electricity and heat consumption was set to 0.4 and 3 kWh/kg laundry respectively, a country-average supply mix of electricity was used and the heat was generated using diesel.

The normalized result for all impact categories are presented in Figure 21.

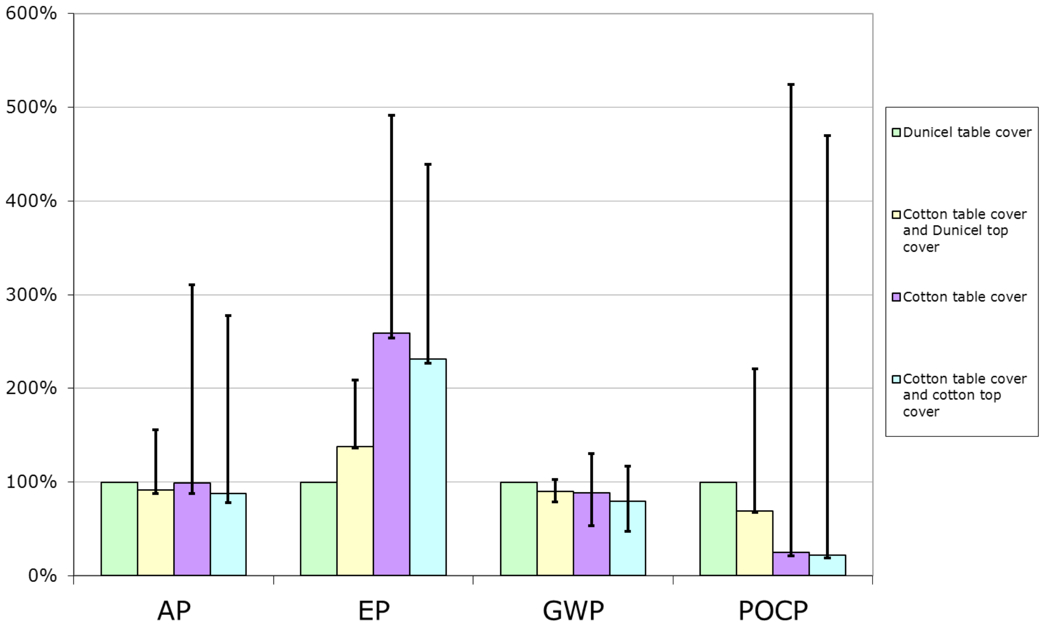

Figure 21 Sensitivity analysis of the importance of the assumed electricity mix and energy consumption at laundry service. The coloured bar represents the base case, the top end of the error bars represents the high emission scenario while the lower end of the error bars represents the low emission scenario. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that the high emission scenario generates a large increase in environmental impact for the systems with only reusable table/top covers with regard to POCP, EP and AP (see the top end of the error bar compared to the coloured bar). For the system with a reusable table cover and a single use top cover, the increase in environmental impact is smaller. The large difference in POCP is caused by the replacement of natural gas to diesel for the generation of heat. Looking at GWP, the increase in environmental impact in the high emission scenario is smaller than for the other impact categories, which can be explained by the fact that both natural gas and diesel which are used for generating heat are both fossil fuels.

Looking at the low emission scenario, there is little difference compared to the base case for all product systems with regard to AP, EP and POCP (see the lower end of the error bar compared to the coloured bar). For GWP, the decreased impact is mainly due to the change in electricity mix, from German supply mix to electricity from hydropower, and decreased electricity consumption. By looking at the figure, it can thus be concluded that changing the electricity mix on the German market to renewable electricity will mainly decrease the global warming potential, while the impact for the other impact categories almost do not change at all.

C.1.3 Low-carbon electricity at Bramsche manufacturing site

In the base case, a German supply mix of electricity is used for the converting facility in Bramsche. In this sensitivity analysis, electricity from hydropower was instead used.

The normalized result for all impact categories are presented in Figure 22.

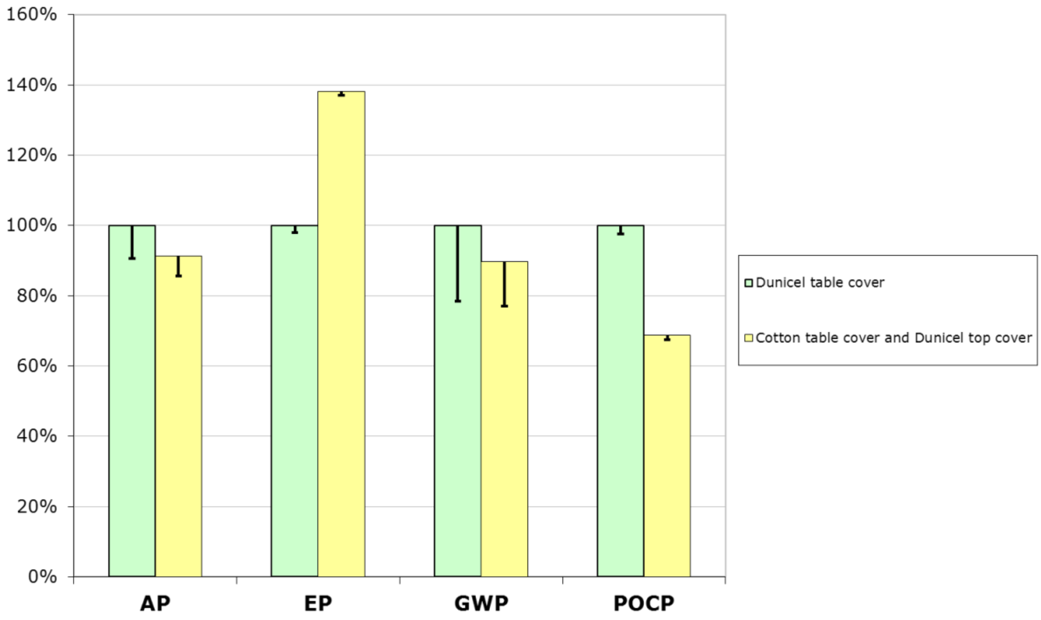

Figure 22 Sensitivity analysis of the importance of renewable electricity at the Bramsche manufacturing site on the German market. The coloured bars show the base case and the error bars shows the scenario with low-carbon electricity at Bramsche manufacturing site. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

The results show that by changing electricity at the Bramsche manufacturing site, from German country-average supply mix to electricity from hydropower, the environmental impact for the single use table/top covers are reduced or approximately equal for all impact categories compared to the base case. The largest reduction can be seen for GWP. This entire reduction in environmental impact is attributed to the life cycle phase manufacturing.

C.1.4 Recycling of Dunicel

In the base case, it is assumed that the Dunicel material is treated together with municipal solid waste and is not recycled. In this sensitivity analysis, it is instead assumed that the Dunicel material is recycled. Yield of tissue, energy consumption, chemical consumption and water consumption for the recycling process was obtained from IPPC (2001). In the recycling process, it is assumed that the ingoing material of the Dunicel material is separated followed by recycling of tissue while the glue and fillers are assumed to be incinerated.

To generate one kg of recycled tissue, it has been assumed that 2 kg Dunicel material, 20 g chemicals, 8 litres of water, 1.2 kWh electricity and 1.9 kWh heat is needed.

In Figure 23 and Figure 24 below, the result from this sensitivity analysis is presented.

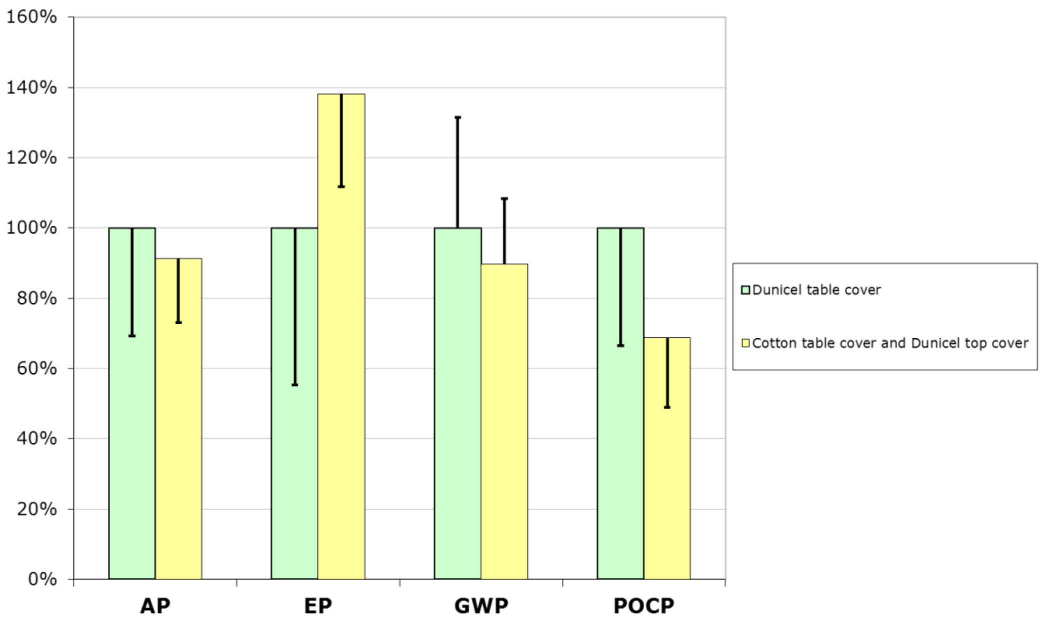

Figure 23 Sensitivity analysis of the importance of recycling tissue on the German market. The coloured bars show the base case and the error bars shows the scenario with recycling of tissue. Abbreviations: AP (Acidification Potential), EP (Eutrophication Potential), GWP (Global Warming Potential) and POCP (Photochemical Oxidant Creation Potential).

In Figure 23, it can be seen that by recycling the Dunicel material, the acidification potential, eutrophication potential and photochemical creation potential is reduced. This reduction is caused by the fact that recycling tissue causes less environmental impact that producing tissue from virgin materials.

For GWP, there is an increase in environmental impact when recycling tissue compared to using virgin material. This is due to the virgin tissue being produced in Sweden using the Swedish country-average supply mix while the recycling of tissue in this sensitivity analysis takes place in Germany using German country-average supply mix, which gives rise to higher CO2 emission per kWh than the Swedish supply mix. This can be seen in Figure 24 below where the CO2 emissions for the different life cycle stages are presented. In the figure, it can be seen that the CO2 emissions from the waste management are higher than the emissions from avoided emissions, thereby generating a net increase in emissions.

If the recycling instead took place on the Swedish market, it is likely that emissions from the waste management would be lower than on the German market, thereby generating a smaller difference between the generated emissions during waste management and the avoided emissions from not having to produce tissue from virgin materials.

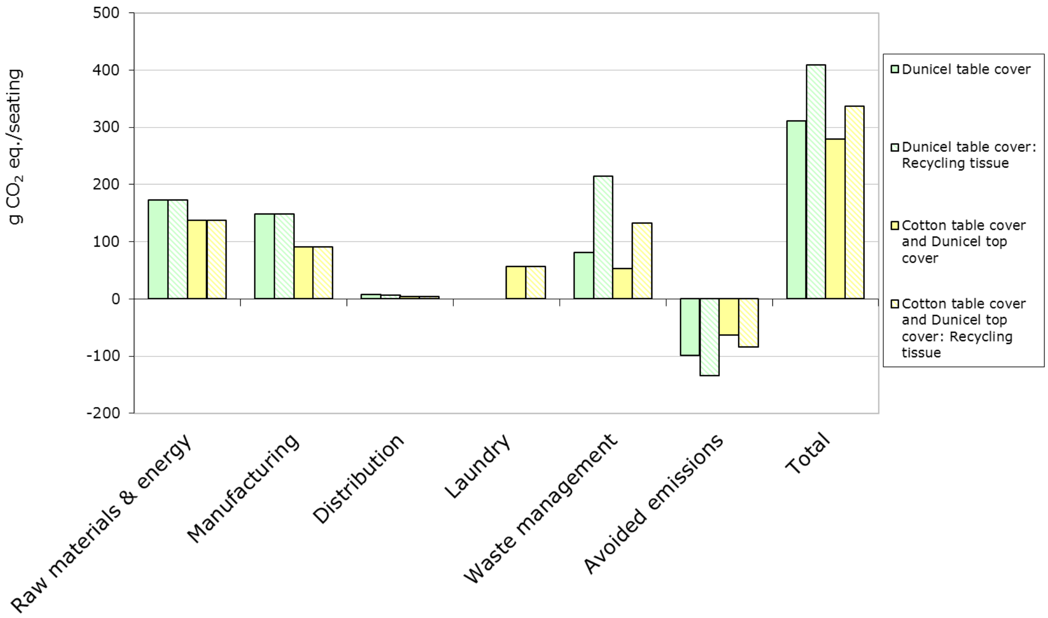

Figure 24 Sensitivity analysis showing the emissions of CO2 for the base case and for a scenario with recycling of tissue on the German market.

C.2 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 10.

Table 10 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	Dunicel table/top covers	30 g sodium hydroxide / kg Dunicel	Up to 4% impact on different categories for Dunicel table/top covers	Yes
Material losses during weaving	Cotton table/top covers	2% material losses during weaving	Up to 2% increased impact in different impact categories for cotton table/top covers	Yes
Sizing agent used at weaving	Cotton table/top cover	225 g modified starch / kg of textile	Up to 4% increased impact in different impact categories for cotton table/top covers	Yes
Emissions to water during weaving	Cotton table/top covers	COD of 35 mg PO_4^{3-} eq/g sizing agent	Up to 10% effect on EP, no effect on AP, GWP, POCP for cotton table/top covers	Yes

Data gap	Affected systems	Assumption	Effect on total results	May affect conclusions?
Detergent, bleach, starch and softener at laundry facility	Cotton table/top covers	Production of 20 g of zeolite powder / kg of laundry	Up to 4% increased impact in different impact categories for cotton table/top covers	Yes
Transport packaging for distribution of textile table/top covers	Cotton table/top covers	Production of 25 g plastic foil (PP) / kg table/top covers distributed	<1% impact for AP, EP, GWP and POCP for cotton table/top covers	No
Transport packaging for return transport from laundry service	Cotton table/top covers	Production of 25 g plastic foil (PP) / kg table/top covers transported to laundry	Up to 15% increase on POCP, approximately 8 % increase on GWP and AP and 1% increase on EP for cotton table/top covers	Yes

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

For single-use table/top covers, 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 table/top covers, more data gaps were identified than for single-use table/top covers. This was expected as these are estimated alternative products modelled in order to compare the environmental performance of the use of single-use table/top cover. Data gaps regarding the laundry phase of the table/top covers were found to be significant as the environmental impact of washing a table/top cover is directly related to the use of a table/top cover. So were the data gaps in the production of the table/top covers.

C.3 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 data sources, system boundaries, etc., of the table/top covers were the same, why there should be no problem in comparing the total results of these table/top covers. To be able to adapt the study to the International EPD System, waste management and avoided emissions due to generated electricity and heat were added in a separate life cycle phase for all table/top covers. The functional unit was defined as “providing table cover for one seating at an average restaurant” to have a common unit of comparison for the different table/top cover types.

Section A.5 lists other potential issues for the comparability of the systems. Data gaps are treated in Section C.2, 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 table/top covers as no specific data was available for these table/top covers. The data gaps should, however, all work to make the total results an underestimate of the total impact of the reusable table/top covers.

Another area where it could be a problem to have specific data for single-use table/top covers, but not for reusable table/top covers is the site-specific versus national average electricity production. The single-use table/top covers benefit, for instance, from a paper production where the purchased electricity causes low emissions of carbon dioxide. The reusable table/top covers could benefit greatly from buying specific electricity for laundry service as seen in Section C.1.2, 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 table/top cover and as a first step towards EPD:s of Dunicel table/top covers. The results should, however, preferably be interpreted and communicated conservatively.

C.4 Dominance analysis

In the dominance analysis, the results are analysed in terms of which life cycle phases are dominant in contributing to the total environmental impact of the different table cover options.

C.4.1 Life cycle of all table cover options

Here, the results were analysed in terms of which life cycle phases were dominant in contributing to the total environmental impact of the different options. The results per life cycle phase for all environmental impact categories for the three markets are available in Section 3 or Appendix B.

Dunicel table cover

For the Dunicel table cover, the most important life cycle phase is the production of raw materials and energy for almost all impact categories and markets. For GWP, the manufacturing is also an important life cycle stage.

Cotton table cover and Dunicel top cover

As for the Dunicel table cover, the most important life cycle phase for the cotton table cover and Dunicel top cover in the production of raw materials and energy. The second and third most important life cycle stages for this system are manufacturing and laundry.

Cotton table cover

For the reusable cotton table cover, the main contributing life cycle phase is the laundry. When increasing the number of seatings that the table cover is used, the impact from the life cycle phase production of raw materials and energy will be reduced while the laundry will become an even more dominant life cycle phase.

Cotton table cover and cotton top cover

As for the cotton table cover, the most important life cycle phase is the laundry. The same trends can also be observed when increasing the number of seatings.

Appendix D Personal communication

References, personal communication

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

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