Assessing the Environmental Impacts of Disposable Facial Tissue Use versus Reusable Cotton Handkerchiefs

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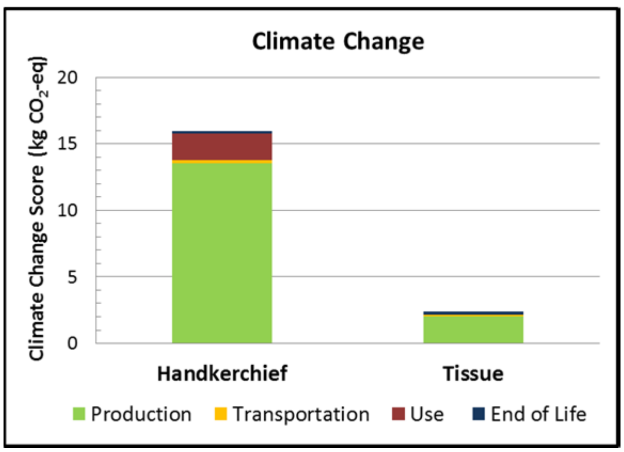
Executive Summary

Household use of disposable facial tissue can add up – a Kimberly Clark LCA reports that affluent households in the Eastern U.S. purchase and use 5,600 sheets of facial tissue a year per household (Madsen, 2007). A previous LCA on reusable handkerchief versus disposable tissue use (Blackburn, 2009) found that handkerchiefs were environmentally superior, but the study only computed impacts for energy, water use, and waste, and also assumed a much longer lifespan of the handkerchief (520 washes) compared to previously published LCAs on textile products (50 washes) (Laursen et al., 2007; Collins & Aumonier, 2002). For this process LCA, the cradle-to-grave environmental impacts of disposable, virgin-paper facial tissues and reusable cotton handkerchiefs were evaluated using a functional unit (nose blows/area) which assessed the variations in product usage over one year's worth of respiratory illnesses and base, well-periods. Use scenarios for an average American adult living in New England were constructed and modeled to better understand how impacts can vary based on intensity of use, frequency of use, and time length of use, taking into account published information on nose blowing frequency in colds and frequency of respiratory illnesses (Dick et al., 1987; Yale & Liu, 2004).



In calculating the environmental impacts for the functional unit, this LCA found that there is no environmental advantage to using reusable handkerchiefs versus disposable facial tissue. All 4 endpoint impact categories – Climate Change, Human Health, Ecosystem Quality, and Resources are between 5 and 7 times greater for the handkerchief functional unit than those calculated for the facial tissue functional unit. Facial tissue end-of-life disposal, the prime reason why many would consider switching to handkerchiefs, only accounted for 10% of climate change impacts.

For all one-year use scenarios, disposable facial tissues had lower environmental impacts in every IMPACT 2002+ midpoint and endpoint category relative to handkerchief use. Using handkerchiefs exclusively was only found environmentally preferable when used for the entire useful life of the handkerchief (50 washes, or 9.4 years), following a use pattern that led to the lowest handkerchief versus facial tissue use rate for the same number of nose blows (1 handkerchief vs. 5 tissues), due to higher intensity of handkerchief use prior to washing.

The electricity used in initial manufacturing of the handkerchief (producing the cotton yarn and weaving the cotton) dominated the impacts for all the use scenarios. Even with over 9 years of handkerchief washing, 65% of the climate change impacts are still due to handkerchief production. The impacts of electricity production (coal mining, coal burning, and coal ash disposal) dominated the Human Health, Climate Change, and Resources categories for handkerchiefs, due to the heavy reliance on coal-derived electricity in the Chinese electricity mix. However, even when handkerchief manufacturing was modeled for the functional unit using a European electricity mix (and facial tissue production modeled with a majority Chinese electricity mix), facial tissue use for one year still resulted in 3 times higher climate change impacts.

Modeling the impacts with an alternative impact assessment model did not alter the overall conclusions. For most users, facial tissues are the environmentally preferable choice. Handkerchief manufacturers would gain the greatest environmental impacts by decreasing the electricity used in cotton textile weaving and yarn production.

1 Introduction

Environmental concern over the accumulation of municipal waste and use of resources has led to an increase in interest in reusable products in the United States. Use of reusable shopping bags are on the rise (Associated Press, 2011), and major US cities have either tried to ban or are considering banning stores from providing plastic bags at checkout (Chanoff, 2012; Lopez, 2012). Sales of reusable cloth diapers have become a niche market (Associated Press, 2009), mainly due to the perception that cloth diapers are less environmentally harmful (Associated Press, 2011). However, previous life cycle assessments (LCAs) of nappies have found that cloth diapers and disposable diapers have similar environmental impacts (Aumonier et al., 2008).

Cloth handkerchief use could be another way that environmentally conscience consumers try to decrease their use of reusable products (Megasko, 2011). Household use of disposable facial tissue can add up – A Kimberly Clark LCA reports that an average, affluent household in the Eastern U.S. can purchase and use 5,600 sheets of facial tissue a year (Madsen, 2007). A newspaper article describing a previous LCA on handkerchief versus tissue use (Blackburn, 2009) found that handkerchiefs were environmentally superior, but the study did not define a use based functional unit and also assumed an exceptionally long life of the handkerchief (520 washes) compared to previously published LCAs on textile products (50 washes) (Laursen et al., 2007; Collins and Aumonier, 2002). In this LCA, I have set out to comprehensively assess the environmental impacts of production, transportation, use, and disposal of disposable paper handkerchiefs and reusable cotton handkerchiefs with a functional unit (nose blows/area) which looks at the product use versus just the relative product masses.

2 Methodologies

The overall impacts of a product, service, or organization can be difficult to assess with a cursory analysis. An evaluation whether it is “green” or not is often based on the amount of waste generated or the energy or water used in production. However, this can give an incomplete picture. Life Cycle Assessment (LCA) was developed to assess a product’s overall environmental impacts over the entire life cycle of the product, including the production, transportation, use, and disposal of the product. LCA can be conducted to find areas for environmental performance improvements, assist in decision making, and support marketing and labeling campaigns.

To allow for the comparison of multiple products in LCA, a **functional unit** is carefully chosen. The functional unit expresses the shared functions of the studied products in quantitative terms and serves as the basis of LCA calculations and the unit of comparison.

LCA is comprised of 4 phases: (1) **Goal and Scope Definition**, (2) **Inventory Analysis**, (3) **Impact Assessment**, and (4) **Interpretation**. During **Goal and Scope Definition**, the purpose of the LCA is specified, the functional unit is developed, the boundaries of the LCA are determined, and important assumptions are stated. The **Inventory Analysis** stage consists of developing a complete log of material, energy, and pollutant release flows through the life cycle, often with the assistance of LCA databases. As part **of Impact Assessment**, the emissions and resources used are combined into a set of impact categories with the help of impact assessment models. Finally, the meaning and results of the inventory and impact assessment are evaluated relative to the stated goals of the study as part of **Interpretation**. As with all life cycle assessments, the completion of this LCA has been an iterative process, in which the findings at each stage influence changes in the other stages, with the overall mission to meet the defined goals of the LCA.

2.1 Goal and Scope

2.1.1 Objective

The goal of this life cycle assessment (LCA) is to determine if an average American adult living in New England switched from use of disposable paper facial tissue to reusable cotton handkerchiefs, would this result in lower environmental impacts.

The objectives of this LCA are:

A. To describe the environmental impacts of use of disposable facial tissue and reusable cotton handkerchiefs over the whole life cycle of the products.
B. To compare the environmental impacts of use of disposable facial tissue and reusable cotton handkerchiefs, taking into account variations in intensity of use, frequency of use, and time length of use.

This study has been commissioned by Ecosystem Analytics Inc. as an example of the company's expertise in life cycle assessment for clients. It will be web available, and therefore, available to the public. This study includes a comparative assertion and is planned to be disclosed to the public. Ecosystem Analytics Inc. did not directly work with the producers of facial tissue and cotton handkerchiefs, but instead relied on data from peer-reviewed data sets and previously published LCA studies.

For the purpose of this study, facial tissue and handkerchiefs are assumed to be only used to blow one's nose. I acknowledge that facial tissue and handkerchiefs can be used for other sanitary uses such as washing glasses and cleaning up spills, but it is assumed that the average user would preferentially use products better designed for those uses.

All data described here are estimates of potential impacts, versus direct measurements of real impacts.

2.1.2 Functional Unit

The primary functions of both paper facial tissue and cloth handkerchiefs are absorbency and hygiene.

Therefore, the functional unit for this LCA is defined as the number of nose blows per surface area for an average American adult over 1 calendar year, encompassing the use pattern during 4 respiratory illnesses(896 nose blows) and daily use during well periods (337 nose blows). This scenario represents a middling case of the total number of facial tissue versus total number of handkerchiefs used. 5 other one-year scenarios are considered in the sensitivity analysis. A summary of the functional unit and how it corresponds to facial tissue and handkerchief use can be found in Table 1.

Table 1: Product Characteristics

	Disposable Facial Tissue	**Reusable Handkerchief**
		
Functional Unit	nose blows per surface area for an average American adult over 1 calendar year, encompassing the use pattern during 4 respiratory illnesses (896 nose blows) and daily use during well periods (337 nose blows).	
Use Pattern	respiratory illness: 2 nose blows/facial tissue well periods: 1 nose blow/facial tissue	respiratory illness: 8 nose blows/handkerchief well periods: 1 nose blow/handkerchief
Total Product Amount to Fulfill Functional Unit	785 facial tissues	449 handkerchiefs
Reuse and Laundering	none	30 handkerchiefs in circulation, all washed as part of household laundry when all 30 are soiled
Product Amount to Fulfill Function Unit Including Reuse	785 facial tissues	30 handkerchiefs used and washed 14.97 times
Description	200 count 2-ply white facial tissues from leading U.S. brand	6 pack 100% cotton handkerchiefs distributed by major U.S. retailer
Product Specifications of Single Facial Tissue or Handkerchief	8.2 x 8.4 in. (20.8 cm x 21.3 cm) 68.9 in^2 (443 cm^2) 1.29 g	16 in. x 16 in. (40.64 cm x 40.64 cm) 256 cm^2 (1,652 cm^2) 15.0 g
Packaging	Printed cardboard box with polyethylene (PE) insert	Printed cardboard box with polyethylene (PE) sleeve, each set of 2 handkerchiefs rolled around a piece of Kraft paper
Packaging Specifications	cardboard box: 59 g PE insert: 2 g	cardboard box: 42 g PE sleeve: 14 g paper: 6 g (2 g each)
Packaging Specifications per Single Facial Tissue or Handkerchief	cardboard box: 0.295 g/facial tissue PE insert: 0.010 g/facial tissue	cardboard box: 7 g/handkerchief PE sleeve: 2.3 g/handkerchief paper: 1 g/handkerchief
Manufacturing Location	Ontario, Canada	China
Supply Chain Distances	1550 km by rail to Northeast U.S.[A] 777 km by truck in Northeast U.S.[A]	11,814 km by ship from Hong Kong to L.A. 4,025 km by rail from L.A. to Northeast U.S. 777 km by truck in Northeast U.S.[A]
End of Life	landfilling, incineration	landfilling & incineration for packaging only sewage treatment for laundry water

[A] - Derived from the Ecoinvent 2.2 unit process, Paper, newsprint, at regional storage/RER since the distances were in line with those estimated.

Madsen (2007), in an LCA for Kimberly Clark evaluating the environmental impacts of facial tissue, also identified strength and softness along with absorbency and hygiene as primary functions of facial tissue. Image, luxury, quality, and consumer satisfaction were noted as secondary functions of facial tissue (Madsen, 2007). Although strength can be a function of absorbency and the number of nose blows that the product can withstand, the other characteristics highlighted in the Madsen study such as softness, luxury, imagine, and quality are subjective in nature and are beyond the scope of this LCA. Although some facial tissues on the market contain additives such a scent, lotion, and anti-viral compounds, a standard facial tissue was purposely chosen for this LCA so that such secondary functions would not need to be assessed.

2.1.2.1 Functional Unit Creation

2.1.2.1.1 Nose Blow Frequency

The frequency of nose blows can vary considerably between periods of respiratory illnesses and day to day sneezes. Luckily, medical investigations on transmission and treatment of the common cold can help shed light on the frequency of nose blows during sickness. For a study on the transmission of rhinovirus colds by aerosols, Dick et al. (1987) counted the number of times 12 participants blew their nose in a 12 hour study period in 4 separate experiments. The 12 study participants were at various levels of sickness by the virus, thus giving a good average of nose blows over the duration of a cold. In what I deem the “Max Cold”, the 12 participants blew their nose 292 times, resulting in 24 nose blows a person in 12 hours (2 nose blows/hour). In the “Min Cold” scenario, the 12 study participants blew their nose 136 times, resulting in 11 nose blows per person in 12 hours (0.92 nose blows/hour). I have assumed that the average sick person sleeps for 8 hours, but the other 16 hours are available for nose blowing. According to Yale and Liu (2004), the average length of a cold is 7 days, and the average American adult has 2 to 4 colds a year.

In creating the functional unit, the number of nose blows during respiratory illnesses was based on the Max Cold scenario (2 nose blows/hour) for 16 hours/day over the duration of an average cold (7 days) for 4 colds in 1 year (the high end of the range cited by Yale and Liu (2004)). This resulted in 896 nose blows per person per year due to respiratory illnesses. Scenarios that are based on the Min Cold frequency of nose blows (0.92 nose blows/hour) for 16 hours/day over the duration of the cold (7 days) for 2 colds in 1 year are also considered during sensitivity analysis, as well as No Cold scenarios.

Most people do not only blow their nose during colds. For the remaining 337 days of the year that the average American adult is not ill with a respiratory illness, I assumed that he blows his nose once a day, or 337 additional times in a year.

2.1.2.1.2 Nose Blows per Facial Tissue or Handkerchief

Since no use studies have been published on facial tissue or reusable handkerchiefs, a range of the permissible number of nose blows was determined based on the relative surface areas of the products. A standard-sized facial tissue (8.2 by 8.4 inches in. size, 68.9 in.^{2} surface area) is assumed to allow for 1 to 2 nose blows. A handkerchief, which is approximately 4 times as large as the facial tissue (16 inches by 16 inches square, 256 in.^{2} surface area) is assumed to be able to handle between 1 to 8 nose blows.

During colds, given the high frequency of nose blowing, the facial tissues or handkerchiefs will be used more extensively. During respiratory illnesses, I have assumed that the average American will blow his nose 2 times per facial tissue and 8 times per handkerchief, in proportion to their relative surface areas. Using this relationship, 448 facial tissues or 112 handkerchiefs are used during illnesses as part of the functional unit

During everyday base use, the use pattern of disposable facial tissues and reusable handkerchiefs can vary. For example, if the user stored a facial tissue or handkerchief in his pants pocket, the user would likely dispose of the tissue after use and place the handkerchief in the laundry after changing his outfit at the end of the day. This scenario is called the Max Base Use scenario, and resulted in either 337 facial tissues or 337 individual uses of a reusable handkerchief. The functional unit incorporates the Max Base Use scenario.

Alternatively, if the tissue or handkerchief is stored in a personal bag or purse, the handkerchief would likely be used multiple times on multiple days before being replaced by a fresh handkerchief. However, the facial tissue stored in a personal bag would still be disposed upon each use. In the "Min Base Use" scenario, one facial tissue would be used each day while one handkerchief would be used for 7 days before replacement with a freshly laundered handkerchief. Min Base Use patterns are incorporated into use scenarios that are part of this LCA's sensitivity analysis.

Overall, the functional unit, based on the Max Cold and Max Base Use scenarios, incorporates the use of 785 disposable facial tissues or 449 handkerchiefs in one year.

2.1.2.1.3 Handkerchief Reuse and Laundering

Although it is reasonable to use 785 disposable facial tissues in a year, a typical user would not go out a purchase 449 reusable handkerchiefs. Instead, the cotton handkerchiefs would be washed and reused over the year. For this LCA, I assumed that the average American would have 30 cotton handkerchiefs. This number is sufficient to get one through the maximum cold scenario without having to do any extra washing. I have assumed that once the individual in each scenario uses up the 30 handkerchiefs, he will do his entire load of laundry. Thus, the handkerchiefs will only be a small fraction of the total laundry, given their small size and weight.

For the functional unit, 785 disposable facial tissues are used in the year, while 30 cotton handkerchiefs are used and washed 14.97 times (449 total handkerchiefs needed/30 handkerchiefs in use).

2.1.3 System Description

For this LCA, disposable paper facial tissue is modeled based on a 200 count 2-ply box of white facial tissues producing by a leading U.S. brand, and obtained at a major regional retail store. Since this LCA was commissioned without the input of this company, the identity of the facial tissue producer is being withheld. Details of the facial tissue and the facial tissue packaging can be found in Table 1.

Cotton handkerchiefs for this LCA are modeled based on a 6 pack of 100% cotton handkerchiefs distributed by a major regional retail store. As with the facial tissues, this LCA was commissioned without the direct input of the handkerchief manufacturer or distributor, and thus, their exact identities are being withheld. The handkerchiefs are white cotton cloth surrounded by perimeter cotton stitching and have a small cloth washing care tag. For the purpose of this study, impacts due to the perimeter thread and small cloth washing care tag are assumed to be negligible and not included. Details of the handkerchiefs and handkerchief packaging can be found in Table 1.

2.1.4 System Boundaries and Characteristics

The environmental impacts of production, transport to retail, use, and disposal of the products and retail packaging are included in this LCA. Transportation between production steps, packaging used to assist shipment between production steps, and disposal of waste products and packaging used during production are included in this LCA as part of the product's manufacturing.

Transportation from retail to the user's residence and transportation from the user's residence to the location of final disposal is not included in this model. Given that the average consumer would purchase other products on a trip to the store, and given the small size and weight of the products, I assumed that the fraction of the trip to the store due to handkerchief or facial tissue purchases is negligible. Likewise, the fraction of the municipal trash's trip in the refuse hauler due to the facial tissue, handkerchief, or packaging is assumed to be negligible. The impacts of warehouses and retail stores used to sell and store these products also are not included in this LCA for similar rationales. In addition, the environmental impacts of production of capital equipment (washing and drying machines, paper plants, textile production plant) are not included.

The impacts due to the fraction of tap water, soap, soap packaging, energy, wastewater treatment, and disposal of soap packaging used to machine wash and machine dry the handkerchiefs in each load of laundry are included in the LCA. The end-of-life disposal of the handkerchiefs themselves are not included in the functional unit or the one-year use scenarios since the time length did not cover the entire useful life of the handkerchiefs. However, for two use scenarios that modeled impacts over the lifetime of the handkerchiefs (50 washes), the end-of-life disposal of the handkerchiefs are included (see Section 2.4.1.2).

2.2 Inventory Data

2.2.1 Data Sources and Unit Processes

Unit processes were constructed using the Ecoinvent 2.2 database. In some instances, unit processes were altered to better model the specific circumstances of production, use, or disposal, based on previously published results. To facilitate modeling both the functional unit and the sensitivity scenarios, the reference flows for production, transport, and disposal were calculated for a single sheet of Kleenex and a single handkerchief. The fraction of packaging production and disposal impacts were applied to the single sheet of tissue or single handkerchief on a mass basis. The reference flows to produce, transport, and dispose of a single facial tissue can be found in Table A1 in the Appendix, as well as the documentation and rational behind the quantitative values. Likewise, the reference flows to produce, transport, launder, and dispose of a single handkerchief can be found in Table A2 in the Appendix.

2.2.2 Assumptions

2.2.2.1 Geographic Relevance

Although the manufacture of facial tissue in this study occurs in Ontario, Canada, the majority of reference flows use European (RER), Swiss (CH), German (DE), and global (GLO) data from the Ecoinvent database. This could potentially lead to a bias since variations in production conditions could exist in Canada. Although the Ecoinvent database does not contain geographically relevant unit processes, it is considered the most comprehensive and reliable LCA database to date (Frischknecht et al., 2007). By creating all reference flows with Ecoinvent processes, all modeled unit processes are based on consistent and complete data. In addition, it is likely that European paper manufacturing is quite similar to Canadian paper manufacturing. Since no specific Canadian electricity mix is included in Ecoinvent 2.2, I assumed that a mix representative of Scandinavian (NORDEL) and Central European (UCTE) electricity producers could model Canadian electricity production (see Table A1, footnote B).

The cotton handkerchief modeled in this LCA was manufactured in China, and uses Ecoinvent unit processes which are primarily based on textile production in China. The reference flow, Textile- woven cotton -at plant/GLO (Global) (Table A2), is built from unit processes modeling yarn production, weaving, and cotton fiber preparation. The electricity mixes in these unit processes are 60- 70% from China, with the rest from either Europe or the U.S. Likewise, the textile refinement unit process relies on 70% of the electricity demands from China and 30% from Italy. Therefore, the additional electricity needed for cutting and sewing is modeled consistently (70% China, 30% Europe).

2.2.2.2 Reference Flows

All reference flows are based on Ecoinvent data, product specifications, or previously published LCAs. Details of the assumptions behind the reference flow choices and amounts can be found in Table A1 and Table A2 in the Appendix. For this LCA, it is assumed that all packaging and disposable products would either be landfilled or incinerated. Recycling and composting are not considered as end-of-life options. The fraction of each product landfilled versus incinerated is based on the average ratio of landfilling to incineration in New England according to The State of Garbage in America report (Van Haaren et al., 2010).

2.2.3 Data Quality

All data in this LCA is derived from product specifications, Ecoinvent 2.2 database, and previously published LCAs. All unit processes are derived from Ecoinvent 2.2, while product specifications and previously published LCAs helped to determine the reference flows. For example, an LCA on paper towels (Eberle & Moller, 2006) helped determine the range of electricity needed per kg for facial tissue production and an LCA on men's cotton briefs (Collins & Aumonier, 2002) gave a representative amount of electricity needed for textile cutting and sewing per kg. Although no data from the specific manufacturers of facial tissue and handkerchiefs was used, the reliance on Ecoinvent unit processes allows for consistent treatment facilitating comparisons of the two products.

2.3 Life Cycle Impact Assessment Method

After all the flows of materials, energy, and emissions have been quantified for the systems with the assistance of Ecoinvent 2.2, the environmental consequences of the flows are determined by translating the emissions into larger impact categories. For this LCA, the impacts of the production, transport, use, and disposal of the two products are evaluated by calculating the Climate Change, Human Health, Ecosystem Quality, and Resources impact categories as defined by IMPACT 2002+ (Jolliet et al., 2003). IMPACT 2002+ was selected as the impact assessment methodology given its wide use in the field and since it first calculates the environmental impacts of 15 more detailed categories (midpoint indicators), and then summarizes the midpoint categories into the 4 endpoint categories (Jolliet et al., 2003). This allows the details of environmental impacts to be assessed while still getting a comprehensive view of ecological impacts.

The 15 midpoint categories calculated by IMPACT 2002+ are: Human Toxicity, Respiratory Effects, Ionizing Radiation, Ozone Layer Depletion, Photochemical Oxidation, Aquatic Ecotoxicity, Terrestrial Ecotoxicity, Aquatic Acidification, Aquatic Eutrophication, Terrestrial Acidification/Nutrification, Land Occupation, Global Warming, Non-Rene cat wable Energy, and Mineral Extraction. All the emissions and elementary flows that affect a midpoint egory are summed and expressed as an amount of a key pollutant or energy quantity for that category. For example, the midpoint damage category of Global Warming, all emissions of greenhouse gases such as CO_2, CH_4, water vapor, nitrous oxide, and CFCs are converted to CO_2 equivalents (CO_2-eq) and summed (Jolliet et al., 2003).

The midpoint categories are further grouped into the 4 endpoint categories. The Human Health damage category is a sum of the midpoint categories that address carcinogenic and non-carcinogenic toxicity to humans (Human Toxicity), respiratory effects in humans (Respiratory Effects and Photochemical Oxidation), Ionizing Radiation, and Ozone Layer Depletion. It is expressed in Disability Adjusted Life Years (DALY), which represents a measure of the loss of "healthy" years of life due to premature death or disability. Although climate change will likely have effects on human health, IMPACT 2002+ does not model them due to high uncertainty in estimating the effects at the time that the model was designed (Jolliet et al., 2003).

Ecosystem Quality sums the midpoint categories that quantify Aquatic and Terrestrial Ecotoxicity, Aquatic Acidification and Eutrophication, Terrestrial Acidification/Nitrification, and Land Occupation. It is expressed in the unit of Potentially Disappeared Fraction of species per square meter per year (PDF*m^2*yr) (Jolliet et al., 2003). PDF*m^2*yr is the percentage of species that disappear from one square meter of earth surface during one year.

The Resources category sums the energy requirements (in megajoules, MJ) of Non-Renewable Energy and Mineral Extraction along with the extra energy it will take to extract those resources in the future since there will be less of them due to present consumption (Jolliet et al. 2003). The Climate Change endpoint category only sums the impacts of the Global Warming midpoint category, and therefore, provides a good summary of the carbon footprint.

To evaluate the robustness of environmental impacts using IMPACT 2002+, LCA results were also computed for the two product scenarios using a newer impact assessment method, ReCiPe 2008. For details, see Section 2.4.3.

2.4 Scenarios and Sensitivity Analysis

2.4.1 Use Scenarios

2.4.1.1 One-Year Use Scenarios

The functional unit is based on a use profile that results in a middling scenario in the difference in facial tissue consumption to reusable cotton handkerchief use (see section 2.1.2.1 Functional Unit Creation). Using alternative assumptions on use and the frequency, length, and severity of respiratory illnesses results in 5 other one-year use scenarios (Table 2).

As previously described in Section 2.1.2.1, the use scenarios are based on nose blow frequency during respiratory illnesses and during well, base-use periods. The total number of nose blows during respiratory illnesses is based on 3 scenarios – Max Cold, Min Cold, and No Cold. Max Cold is the upper range of published cold frequency, length, and severity (Dick et al., 1987; Yale and Liu, 2004) – 2 nose blows an hour, 16 hours/day, 7 days/cold, for 4 colds/year. Min Cold is the lower range of the same published studies – 0.92 nose blow/hour, 16 hours/day, 7 days/cold, for 2 cold/year. No Cold scenarios, as the name implies, results in 0 nose blows due to respiratory illnesses. Facial tissue and handkerchief use during respiratory illnesses is based on the relative surface area of the products – 2 nose blows/facial tissue and 8 nose blows/handkerchief.

The rest of the year not consumed by colds is covered by two base use scenarios – Max Base Use or Min Base Use. Max Base Use assumes that the average American adult uses a facial tissue or handkerchief to blow his nose daily, and either disposes the facial tissue or puts the handkerchief in the laundry at the end of each day. This scenario covers an individual who stores a handkerchief in his pants pocket and changes his outfit daily. The Min Base Use scenario also assumes that the individual would still dispose the tissue upon use each day, but assumes that the user would reuse the handkerchief for a week before placing in the laundry hamper. This scenario models situations in which the individual would store the handkerchief in a backpack or purse, and only clean the bag out once a week.

Table 2: Functional Unit and Use Based Scenarios - 1 Year Use

Scenario	Respiratory Illness		Base Use		Total # Tiss. or Handker. Used	# Washes of 30 handker.
	Nose Blows	*# Tiss. or Handker. Used*	*Nose Blows*	*# Tiss. or Handker. Used*		
Functional Unit						
Facial Tissue	2 nose blows/tissue		1 nose blow/tissue			
Functional Unit	896	448	337	337	785	-
Handkerchief	8 nose blows/handkerchief		1 nose blow/handkerchief			
Functional Unit	896	112	337	337	449	14.97
Use Scenarios						
Max Base Use						
Facial Tissue	2 nose blows/tissue		1 nose blow/tissue			
Min Cold & Max Base Use	206	103	351	351	454	-
Handkerchief	8 nose blows/handkerchief		1 nose blow/handkerchief			
Min Cold & Max Base Use	206	26	351	351	377	12.57
Facial Tissue	2 nose blows/tissue		1 nose blow/tissue			
No Cold & Max Base Use	0	0	365	365	365	-
Handkerchief	8 nose blows/handkerchief		1 nose blow/handkerchief			
No Cold & Max Base Use	0	0	365	365	365	12.17
Min Base Use						
Facial Tissue	2 nose blows/tissue		1 nose blow/tissue			
Max Cold & Min Base Use	896	448	337	337	785	-
Handkerchief	8 nose blows/handkerchief		7 nose blow/handkerchief			
Max Cold & Min Base Use	896	112	337	48	160	5.33
Facial Tissue	2 nose blows/tissue		1 nose blow/tissue			
Min Cold & Min Base Use	206	103	351	351	454	-
Handkerchief	8 nose blows/handkerchief		7 nose blow/handkerchief			
Min Cold & Min Base Use	206	26	351	50	76	2.53
Facial Tissue	2 nose blows/tissue		1 nose blow/tissue			
No Cold & Min Base Use	0	0	365	365	365	-
Handkerchief	8 nose		7 nose			

	blows/handkerchief		blow/handkerchief			
No Cold & Min Base Use	0	0	365	52	52	1.73

The 5 one-year use scenarios result in varying relative tissue versus handkerchief use. At the high end, the Max Cold and Min Base Use scenario results in 625 more total facial tissues being used than handkerchiefs. At the low end, No Cold and Max Base Use results in exactly the same number of facial tissues and handkerchiefs used for the year. Although the total number of handkerchiefs used is helpful to illustrate the effects of the use assumptions, only 30 handkerchiefs are assumed to be in circulation. Upon use of the 30 handkerchiefs in circulation, all of them are washed as part of the individual's laundry, thus resulting in the overall number of washes for the year in Table 2.

2.4.1.2 Maximum Life Use Scenarios

Two use scenarios were designed to explore the impacts of facial tissue and handkerchief use over the entire useful life of the handkerchief. Based on previous LCAs on textile products (Laursen et al., 2007; Collins and Aumonier, 2007), 50 washes was used as the maximum life of the handkerchiefs. So, the maximum number of total handkerchiefs used for both scenarios is 1500 (30 handkerchiefs times 50 uses/washes) (Table 3). Two use patterns previously described for the one year scenarios were used for the Max Life scenarios – Max Cold & Max Base Use (basis for functional unit) and Max Cold & Min Base Use (which results in the largest difference in total facial tissue use versus total handkerchief use).

Table 3: Max Life, Use-Based Scenarios

Product	***Total # Tissues or Handkerchiefs Used***	***# Washes of 30 handkerchiefs***	***Years***
Max Life Max Cold & Max Base Use[A]			
Facial Tissue	2622	-	3.34
Handkerchief	1500	50	3.34
Max Life Max Cold & Min Base Use[A]			
Facial Tissue	7359	-	9.375
Handkerchief	1500	50	9.375
[A] - Since the scenarios model handkerchief use over the product's entire useful life, end-of-life was modeled for the handkerchiefs in addition to the packaging and waste from washing. See Table A3 for a summary of the added unit processes and reference flows.			

To determine the number of years it would take to reach 50 washes for all 30 handkerchiefs in the two scenarios, the maximum number of handkerchief uses (1500) is divided by the rate of handkerchief use per year per person. The Max Life Max Cold & Max Base Use scenario covers 3.34 years, while the Max

Life Max Cold & Min Base Use scenario covers 9.375 years. The amount of tissues used for the entire period is obtained by multiplying the yearly tissue use rate per person for each scenario by the number of years calculated. Since the Max Life scenarios model handkerchief use over the product's entire useful life, end-of-life is modeled for the handkerchiefs in addition to the packaging and waste from washing. See Table A3 for a summary of the added unit processes and reference flows.

2.4.2 Country of Production/Electricity Mix Scenarios

The functional unit is modeled to roughly estimate the impacts of production due to the location of manufacturing - Canada for the facial tissue and China for the handkerchief. This is accomplished by choosing an electricity mix that is relevant for the location. Since Ecoinvent 2.2 does not have an electricity mix modeled for Canada, I retained the electricity mix in the paper production unit process in Ecoinvent – 46.75% from NORDEL and 53.25% from UCTE (Table A1). NORDEL is a consortium of electricity system operators from Denmark, Finland, Iceland, Norway, and Sweden. UCTE is the grid operators for Continental Europe. This electricity mix relieves heavily on Scandinavian countries which heavily use hydropower (European Commission, 2011), like Canada (Canadian Hydropower Association, 2009). Cotton textile production processes in Ecoinvent are modeled to reflect the predominance of manufacturing in Asia – with 70% of electricity production from China and 30% from Europe. This electricity mix is retained from Ecoinvent since it reflected the true location of production for the handkerchief while still integrating the possibility that some manufacturing steps occurred outside China in Western countries.

To assess the importance of the electricity mix to the LCA results, two other scenarios were developed – Facial Tissue GLO and Handkerchief RER. For Facial Tissue GLO, the electricity mix for manufacturing the facial tissue is the same as used for the handkerchief in the functional unit (70% from China, 30% from Europe). The scenario Handkerchief RER uses the same mix of electricity as the facial tissue production for the functional unit (46.75% from NORDEL and 53.25% from UCTE). The electricity mix was only altered from processes relating to the production of the actual facial tissue and handkerchief. Electricity used to produce packaging and used in washing steps was not altered. For details, see Table A4 in the Appendix.

2.4.3 Impact Assessment Sensitivity Analysis

Any model, at best, is only a simplified representation of the complex interactions of the natural world. Although based on the best science at the time, inherently the models must contain many assumptions and simplifications to aggregate the predicted environmental pollutants and combine them into damage categories. Comparing the results from another LCIA model, which contains variations in characterization factors, aggregation methodologies, and model assumptions, can help determine the robustness of the life cycle assessment findings. Therefore, the functional unit for handkerchief and facial tissue use is also modeled using ReCiPe 2008, a more recent model designed by the Netherlands Ministry of Housing, Spatial Planning, and Environment (Goedkoop et al., 2009).

Like IMPACT 2002+, ReCiPe 2008 calculates midpoint environmental impact categories and then aggregates them into endpoint impact categories. ReCiPe calculates 17 midpoint categories, 2 more than IMPACT 2002+. The ReCiPe model midpoint categories are: Climate Change Human Health, Ozone Depletion, Human Toxicity, Photochemical Oxidant Formation, Particulate Matter Formation, Ionizing Radiation, Climate Change Ecosystems, Terrestrial Acidification, Freshwater Ecotoxicity, Marine Ecotoxicity, Agricultural Land Occupation, Urban Land Occupation, Natural Land Transformation, Metal Depletion, and Fossil Fuel Depletion (Goedkoop et al., 2009). In general, both models cover similar environmental concerns, with some expanded focus in ReCiPe 2008. The ReCiPe model estimates the impacts of climate change to human health and ecosystem health even at the midpoint level, instead of just calculating the overall CO_2-eq of product production and use. ReCiPe expands the description of impacts on land use. In IMPACT 2002+, land use changes were summed into one midpoint category – Land Occupation. ReCiPe 2008 breaks out land use impacts into 3 categories: Agricultural Land Occupation, Urban Land Occupation, and Natural Land Transformation. ReCiPe also distinguishes between marine toxicity impacts and freshwater impacts unlike IMPACT 2002+, which sums them into Aquatic Ecotoxicity. Other midpoint categories in ReCiPe 2008 (such as Human Health) are more condensed than IMPACT 2002+, which further broke the midpoint categories into categories such as Carcinogens and Non-Carcinogens.

ReCiPe 2008 sums the midpoint categories into 3 endpoint categories – Damages to Human Health (Human Health), Damages to Ecosystem Diversity (Ecosystems), and Damages to Resource Availability (Resources). Like IMPACT 2002+, in ReCiPe 2008, Damages to Human Health are expressed in Disability Adjusted Life Years (DALY), which represents a measure of the loss of “healthy” years of life due to premature death or disability. In ReCiPe, Damages to Ecosystem Diversity estimates the temporary, partial reduction in species diversity in different ecosystems and is expressed in species loss in a year (species.yr). Damages to Resource Availability are measured in U.S. dollars ($) and are an estimate of the additional cost in the future to extract rarer mineral or fossil fuels.

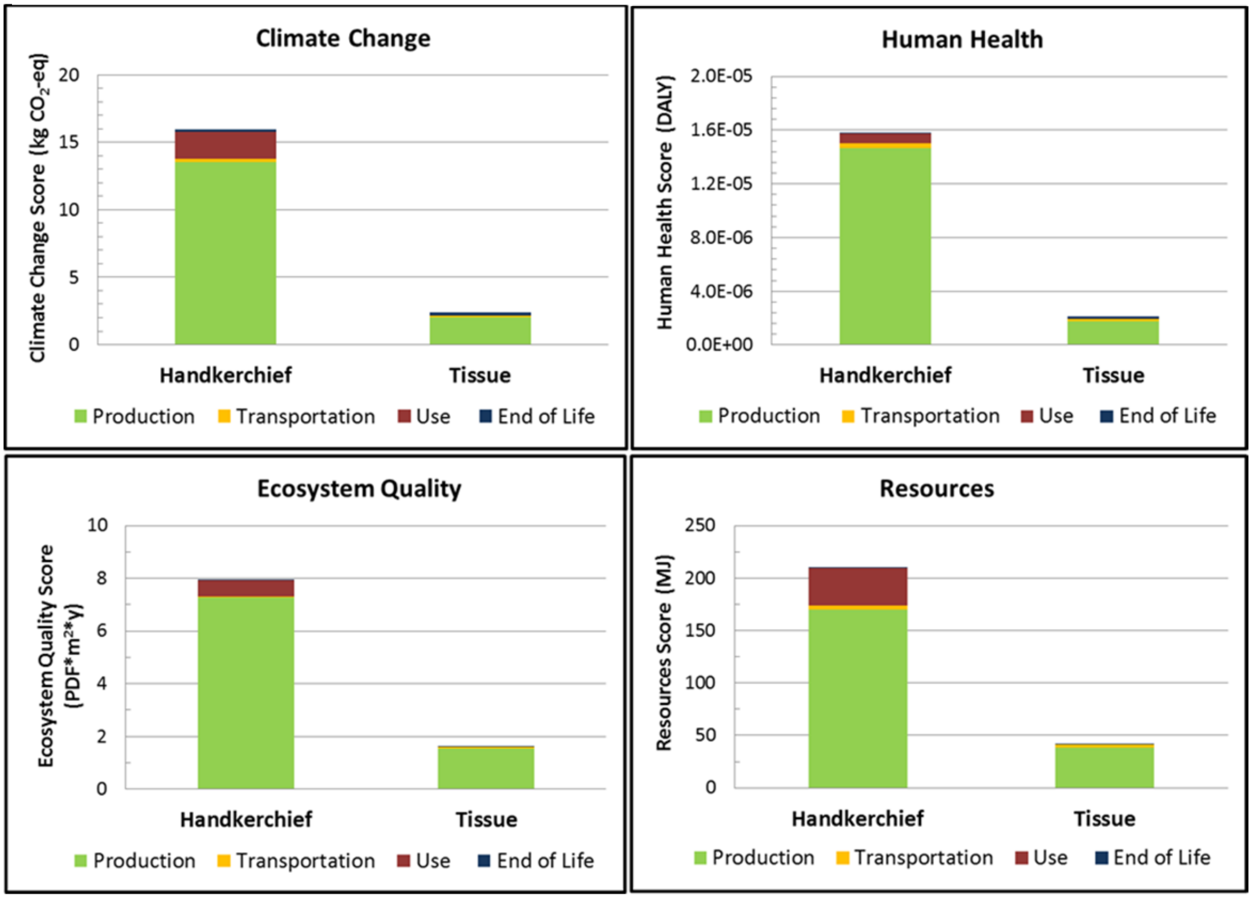
In calculating the midpoint and endpoint categories, ReCiPe utilizes Cultural Perspectives Theory (Thompson et al. 1990) to group categories of assumptions about technological and environmental risk. Cultural Perspectives Theory groups decision makers into 3 groups: Individualists (I), Hierarchists (H), and Egalitarians (E). Calculating the midpoint and endpoint categories using Individualist assumptions results in using the shortest time scales considered and in general, gives the most optimism for technological solutions to environmental problems. Modeling using the Hierarchist assumptions uses the most common policy principles and average time frames for damage estimates. Modeling using ReCiPe 2008 in this LCA is based on Hierarchist (H) assumptions. ReCiPe modeling using Egalitarian (E) perspectives incorporates the most precautionary perspective on environmental damage and the longest time frames for damage assessments.

3 Results

3.1 Summary

In calculating the environmental impacts for the functional unit, this LCA found that there is no environmental advantage to using reusable handkerchiefs versus disposable facial tissues. For the handkerchief functional unit, all four endpoint impact categories, Climate Change, Human Health, Ecosystem Quality, and Resources, are 5X or more higher than those calculated for the facial tissue functional unit (Figure 1). Likewise, the facial tissue functional unit has lower impacts in all 15 midpoint

Figure 1: Total Environmental Impacts for the Functional Unit



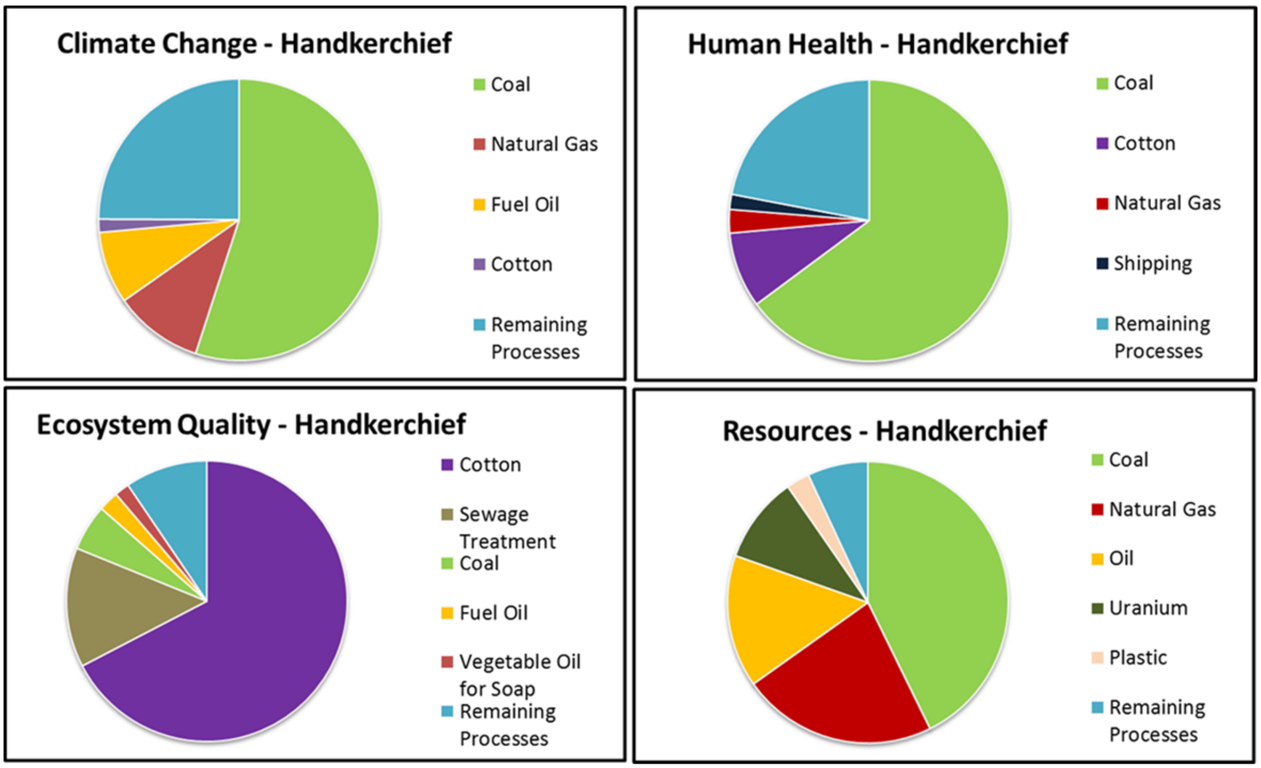
indicator categories used to calculate the endpoint environmental impacts (Table A5).

The environmental damage impacts are dominated by the production of the handkerchiefs or facial tissues (Figure 1). Disposal of the facial tissues accounts for 10% or less of environmental impacts, and washing of the handkerchiefs only contributed between 4 and 17 % of the endpoint impacts (Figure 1).

3.2 Unit Process Contributions

The impacts of handkerchief production, which resulted in over 80% of calculated environmental impacts, are dominated by the manufacturing of the cotton textile and the textile refinement steps (Table A6). The electricity used during textile production and refinement are the biggest driver of the overall environmental impacts, as seen in Figure 2. Coal, the dominant source of energy for electricity production in China where the handkerchief was manufactured, is the single largest contributor for the Climate Change, Human Health, and Resources categories (Figure 2). Cotton production resulted in 67% of Ecosystem Quality impacts (Table A8), but only contributes 2% and 9% of Climate Change and Human Health impacts, respectively.

Figure 2: Unit Process Contributions to the Total Environmental Impacts for the Handkerchief Functional Unit

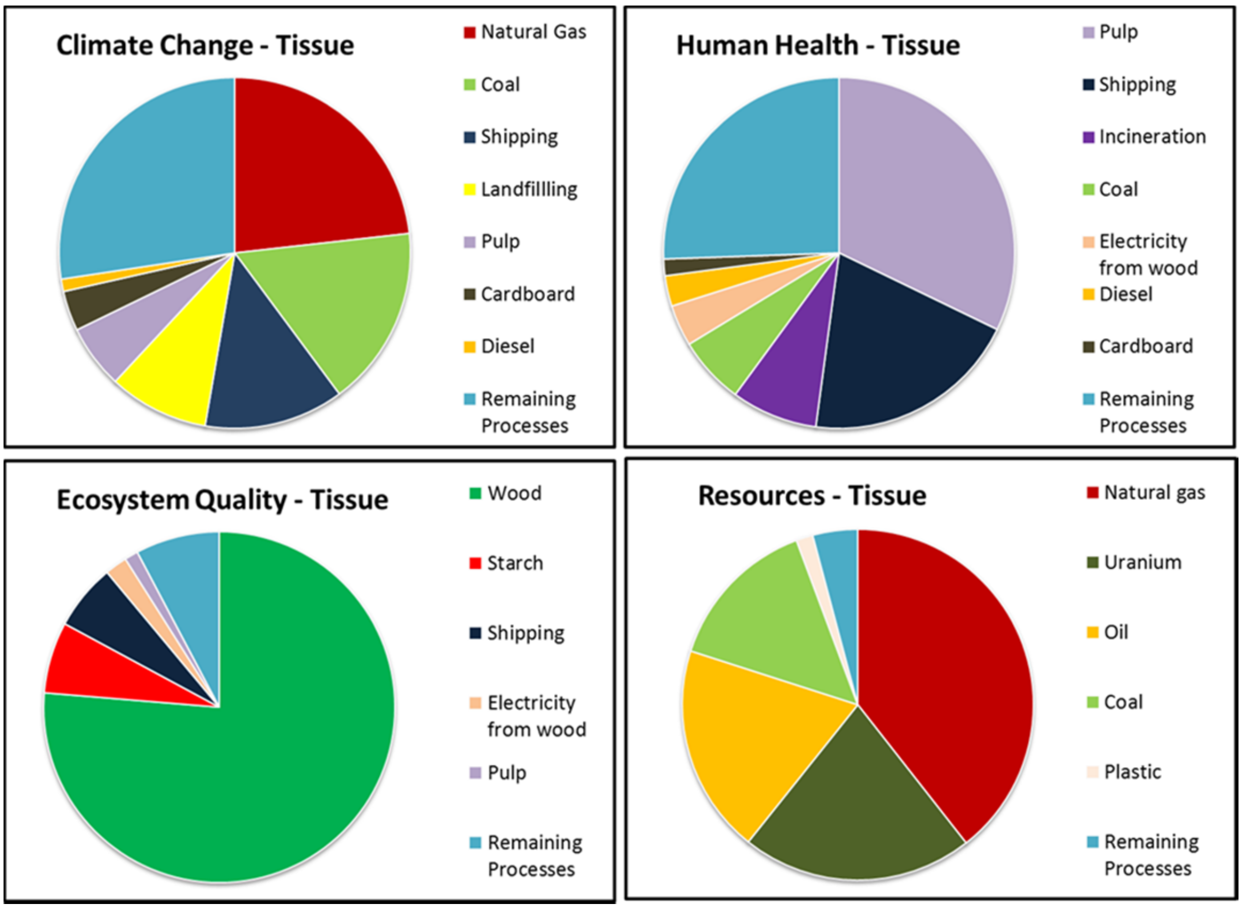


The overall contributors to the environmental impacts of facial tissue production are more varied. The largest reference flow contributor to all 4 damage category scores is pulp production (Table A7). Although the impacts of wood harvesting and pulp production contributes 78% to the Ecosystem Quality score (Figure 3) for facial tissue, unit process associated with pulp production only contributes 6% and 32% to the Climate Change and Human Health scores, respectively (Table A9). Instead, the Climate Change Score is built on the impacts of energy used during paper production (coal and natural gas), shipping emissions, and the impacts of landfilling, along with a myriad of impacts that account for less than 1% each of the overall score throughout the product's lifecycle. Remaining processes represents the second largest unit process contributor to the Human Health score, with shipping, incineration, and coal important unit process contributors (Figure 3). Resources impacts due to facial tissues are derived from the use of fossil fuels (natural gas, coal, and oil) and uranium in electricity production and paper and pulp manufacturing (Figure 3).

3.3 Scenarios and Sensitivity Analysis

To better understand the impacts of use patterns, length of product use, electricity mix, and impact assessment methodology in the findings, alternative use scenarios were constructed and analyzed. This scenario analysis helps determine the sensitivity of the results to assumptions made in creation of the functional unit and demonstrates the robustness of the LCA's results.

Figure 3: Unit Process Contributions to the Total Environmental Impacts for the Facial Tissue Functional Unit

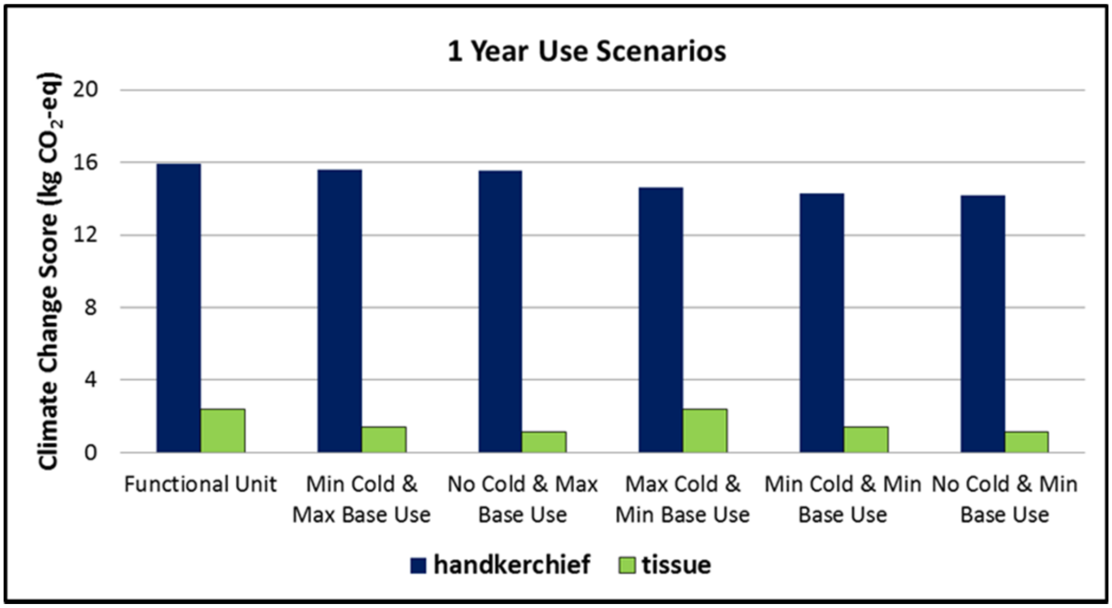


3.3.1 Use Scenarios

3.3.1.1 One-Year Use Scenarios

The functional unit is based on a use profile that results in a middling scenario in relation to facial tissue consumption relative to reusable cotton handkerchief use. As described in Section 2.4.1.1, using alternative assumptions on use and the frequency, length, and severity of respiratory illnesses results in 5 other one-year use scenarios (Table 2). The environmental impacts of these 5 one-year use scenarios were analyzed. As seen in Figure 4, disposable facial tissue use has a lower climate change score than handkerchief use for all 5 of the one-year use scenarios, akin to the results for the functional unit. As also seen in analysis of the functional unit, handkerchief use results in higher impacts for Human Health, Ecosystem Quality, and Resources categories for all 5 one-year use scenarios (Table A10).

Figure 4: Climate Change Impacts from all 1-Year Use Scenarios



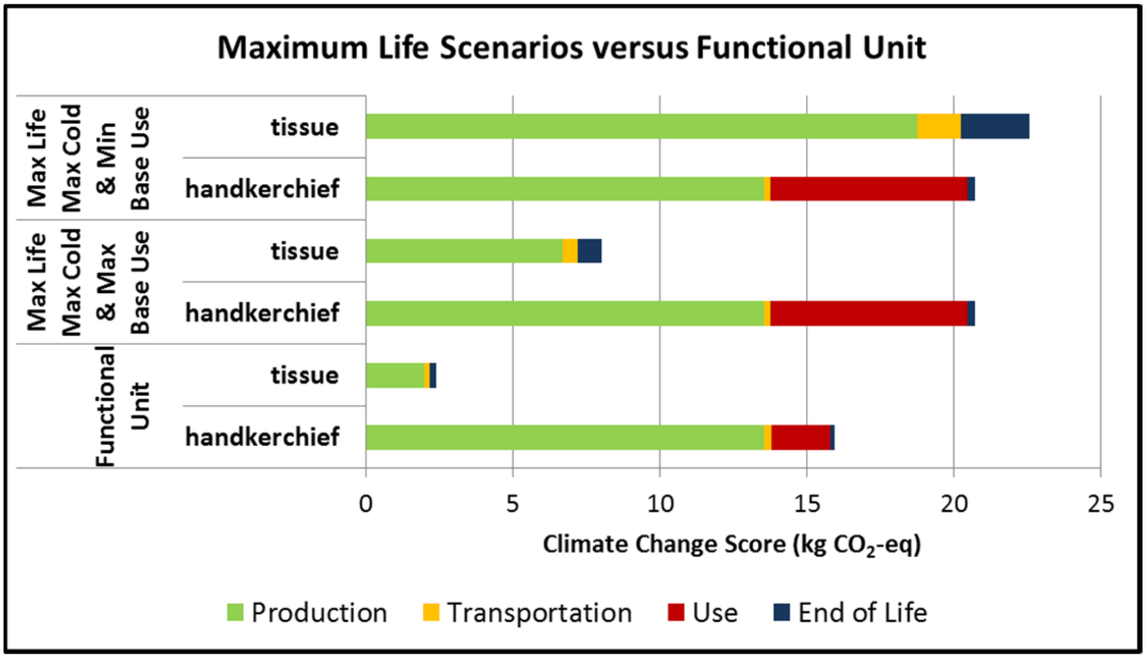
3.3.1.2 Maximum-Life Use Scenarios

Two use scenarios were designed to explore the impacts of facial tissue and handkerchief use over the entire useful life of the handkerchief (50 washes). Extending the assumptions of the functional unit over this time frame and adding the impacts of handkerchief disposal after 50 washes resulted in the Max Life Max Cold & Max Base Use scenario, which covers 3.34 years of use. Extending the one-year use scenario that models the largest number of total facial tissue used versus total handkerchief used created the Max Life Max Cold & Min Base Use scenario. The Max Life Max Cold & Min Base Use scenario covers handkerchief or facial tissue use over 9.375 years and includes the impacts of handkerchief end-of-life after the 50th wash.

As seen in Figure 5, facial tissue use still results in lower climate change impacts relative to handkerchief use when used for over 3 years (Max Life Max Cold & Max Base Use). Human Health, Ecosystem Quality, and Resources are likewise lower for facial tissue use in the Max Life Max Cold & Max Base Use scenario (Table A10).

Handkerchief use is only environmentally advantageous when used for over 9 years following the use assumptions in the Max Life Max Cold & Min Base Use scenario (Figure 5, Table A10). As seen in Figure 5, the climate change score of handkerchiefs for this scenario is only 8% lower than facial tissue use. Handkerchief use in the Max Life Max Cold & Min Base Use scenario also results in a 12% lower Human Health endpoint score, a 38% lower Ecosystem Quality score, and a 24% lower Resources impact (Table A10). The environmental impact reductions upon using reusable handkerchiefs are only achieved upon exclusive use for the entire lifetime of the handkerchiefs, and following a use pattern which only results in handkerchief laundering after a week of daily use in base, non-illness periods.

Figure 5: Climate Change Impacts for the Maximum Life Scenarios



The maximum life handkerchief scenarios include the disposal of the handkerchief along with the handkerchief packaging. However, end-of-life for the handkerchief Max Life scenarios still only represent 1% of the total calculated climate change score (Figure 5), compared to 10% for facial tissues. With 50 wash cycles, the use phase represents a greater percent of the overall climate score relative to the one-year based functional unit (Figure 5). Still, even after 9 years, washing only contributed 32% of climate impacts. 65% of the climate change score is still due to handkerchief production.

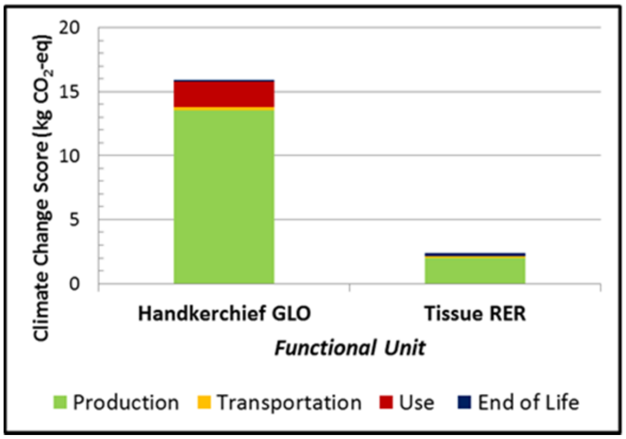
3.3.2 Country of Production/Electricity Mix Scenarios

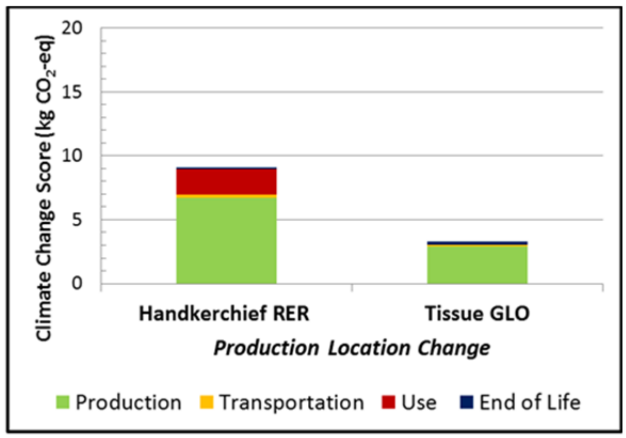
Analysis of the functional unit demonstrates that electricity derived from coal dominates the environmental impacts for handkerchiefs. The global (GLO) electricity mix used to model handkerchief production is predominately derived from an Ecoinvent average Chinese (CN) electricity mix, with 79% of the electricity generated from coal. Since the handkerchief was produced in China, this electricity mix models the system well, while still allowing for the possibility that some upstream production was not in China.

To better understand if the high environmental impacts calculated for handkerchief production is solely due to the choice of electricity mix, I have modeled 2 scenarios in which the country of production and electricity mix for the facial tissue and handkerchiefs are reversed. Handkerchief RER scenario is the same as the functional unit except that the electricity mix used in major production processes is changed to the electricity mix used for the facial tissue functional unit (46.75% from Scandinavia (NORDEL) and 53.25% from Continental Europe (UCTE)). Likewise, Facial Tissue GLO scenario is the same as the functional unit except that the electrical mix is the same as used for the handkerchief functional unit (70% China (CN), 30% Europe (RER).

Although the Climate Change score of Handkerchief RER is lower than the handkerchief functional unit (Handkerchief GLO) while the score of Facial Tissue GLO is slightly higher than the facial tissue functional unit (Facial Tissue RER), Handkerchief RER is still 2.8X greater than Facial Tissue GLO (Figure 6). Human Health, Ecosystem Quality, and Resources score were also lower for Facial Tissue GLO versus Handkerchief RER (Table A11, Table A12). So, even if handkerchiefs are produced in Western Europe with almost half of the electricity from hydropower-rich Scandinavia, a year of using disposable facial tissue made predominately in China still results in lower environmental impacts. Therefore, the higher environmental impacts of handkerchief production are due to high electricity use, versus the reliance of use of coal in the country of production.

Figure 6: Climate Change Impacts for Country of Production/Electricity Mix Scenarios





3.3.3 Impact Assessment Sensitivity Analysis

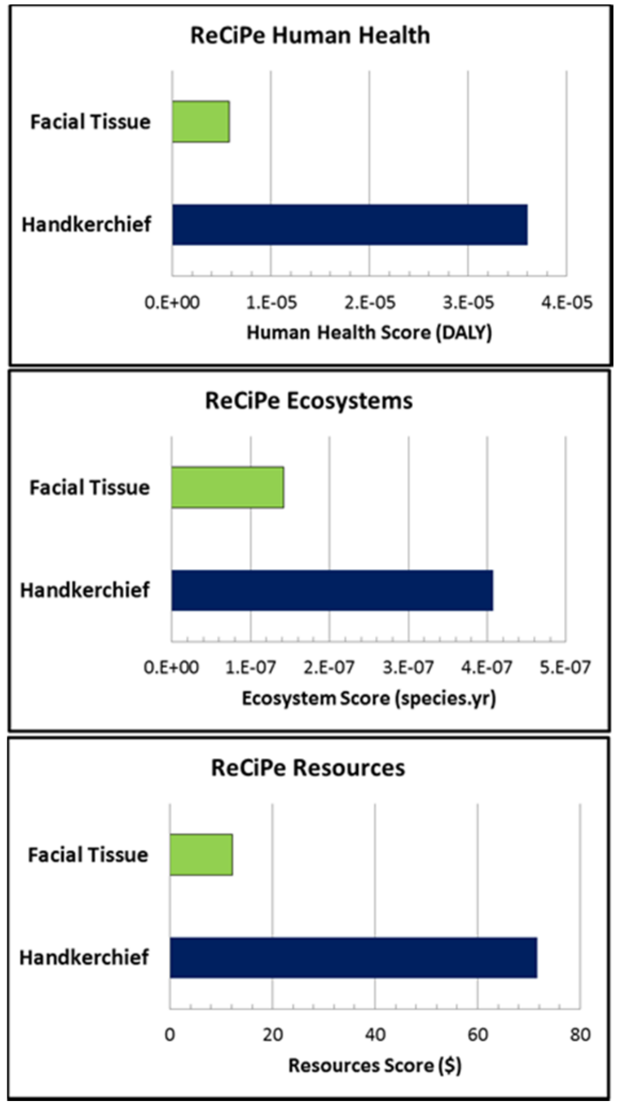
All the previous results are based on the IMPACT 2002+ impact assessment model. To evaluate the role that impact assessment models play in the overall results, the functional unit was also modeled using an alternative impact assessment model, ReCiPe 2008. Like IMPACT 2002+, the model calculates midpoint damage categories, and sums them into endpoints. ReCiPe computes 3 endpoint categories – Human Health, Ecosystems, and Resources. Human health impacts due to climate change and ecosystem damages due to climate change are estimated at the midpoint level and then aggregated into Human Health and Ecosystems endpoints, respectively.

As seen in Figure 7, facial tissue use still has lower environmental impacts when modeled with ReCiPe 2008 for all 3 endpoint categories. Handkerchief use is between 3 and 6 times higher for the 3 endpoint categories compared to disposable facial tissue use (Table A13).

3.4 Comparison with Previous Studies

Blackburn (2009) published a summary of a LCA comparing the water and energy used along with the waste generated from using cotton handkerchiefs and disposable facial tissues. This LCA assumed that the handkerchief would be used and washed 520 times, a 10.4 times longer time length of use than used in this LCA and in other cotton textile LCAs (Laursen et al., 2007; Collins and Aumonier, 2002). Because of the very long life of the handkerchief, the Blackburn LCA found that handkerchiefs use less water, generate less waste, and take less energy to produce per use. Details of the modeling, midpoint indicators, or calculations were not provided. Therefore, a detailed analysis of the results of the two LCAs is not possible.

Figure 7: Environmental Impact Scores from an Alternative Impact Assessment Model (ReCiPe 2008) for the Functional Unit

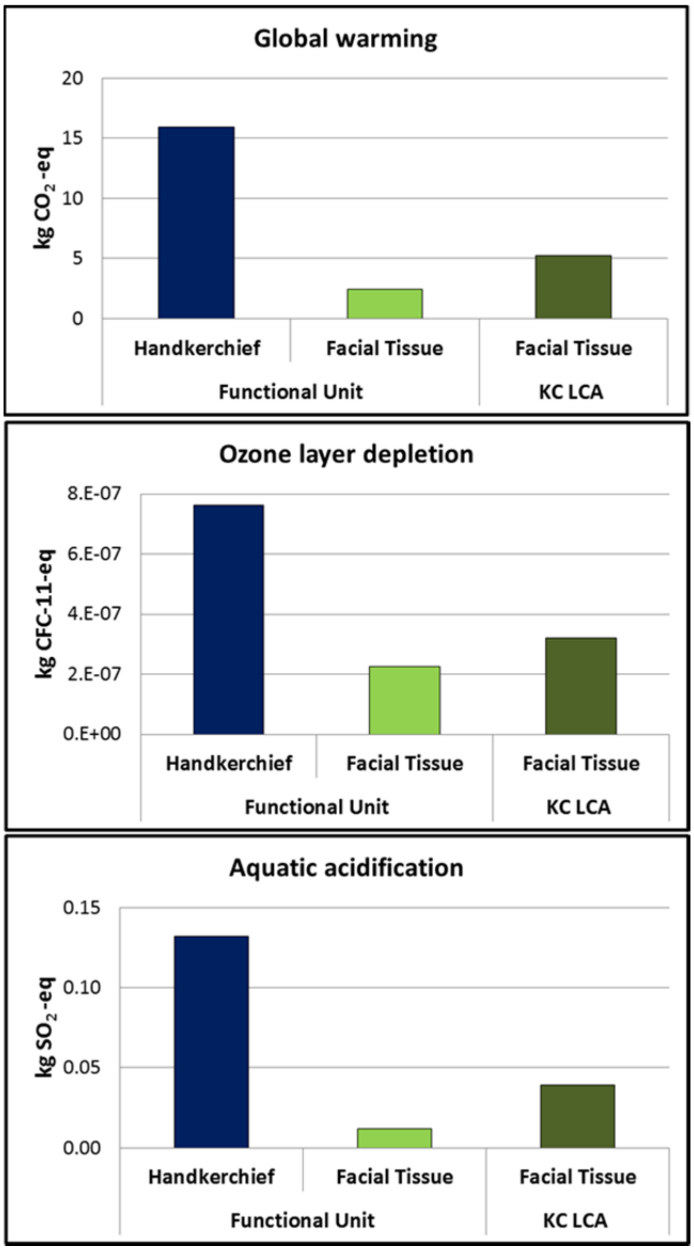


Madsen (2007) analyzed the overall environmental impacts of facial tissue made from virgin pulp in North America for Kimberly Clark. The LCA relied on Kimberly Clark data from their mills and suppliers and was modeled using a different impact assessment model, CML version 2.02. This model calculated impacts at the midpoint level. Three midpoint categories that the Madsen study and this study have in common are Global Warming, Ozone Layer Depletion, and Aquatic Acidification. In IMACT 2002+, these midpoints feed into the Climate Change, Human Health, and Ecosystems Quality endpoint categories.

Midpoint damage impacts for the handkerchief and facial tissue functional unit from this LCA and the Kimberly Clark (KC) LCA can be found in Figure 8. As seen, the 3 midpoint indicators calculated in the KC study are between 30 and 70% greater than the facial tissue impacts calculated in this LCA. This could be due to use of more complete unit processes, less reliance on European data, and use of an alternative impact assessment model. Nonetheless, even with the higher facial tissue impacts from the KC LCA, handkerchief use still results in substantially higher impacts for all 3 midpoint categories. Even in the Max Life Max Cold & Max Base Use scenario which modeled handkerchief use for 3.34 years, the CO_2-eq produced by handkerchief use is still higher than that of the KC facial tissues.

3.5 Study Limitations

Figure 8: Comparison of Midpoint Categories Calculated in this LCA and the Madsen (2007) LCA for Kimberly Clark (KC)



This LCA models the impacts of handkerchief and facial tissue use by constructing the production, transportation, use, and disposal of the products with unit processes from a peer-reviewed, transparent LCA database, Ecoinvent 2.2. Values for the reference flows are either derived from the product specifications, published LCA studies, or the Ecoinvent database (Table A1, Table A2). Given that all the unit processes are from Ecoinvent, the consistency in this LCA is high and the information quality is sufficient to meet the goals of the study. Detailed information on the production of handkerchiefs and the upstream steps from the manufacturer could improve the LCA. However, as observed with the Madsen (2007) LCA, even when facial tissue production is modeled using brand specific manufacturing information, the overall results are not substantially different and do not change the conclusions of the LCA. Given the large difference in environmental impacts calculated in the LCA, I do not believe that factory specific information would alter the overall conclusions.

Although the locations of production are Canada and China for the products, and the location of use and disposal is the United States, this LCA heavily relies on European unit processes from the Ecoinvent database. Location specific impacts are modeled by altering the electricity mix in unit processes. However, the underlying emission data is generally based on efficiency and pollution production profiles from European plants. This could underestimate the overall impacts of both products. However, given the high level of consistency, it is unlikely that relying on Ecoinvent data could cause the overall conclusions to change.

Although the major producer of facial tissue in the U.S. manufacturers the product in Ontario, Canada, this LCA relied on a European electricity mix with nearly half the power from hydropower-rich Scandinavia since an electrical mix for Canada is not available in Ecoinvent 2.2. Eastern Canada heavily relies on hydropower for energy production (Canadian Hydropower

Association). If a Canada- specific energy mix was formulated and used to model facial tissue production, it would likely decrease the overall impacts of facial tissue production. However, this would not alter the overall conclusions of the study.

In modeling the cradle-to-grave impacts of handkerchiefs and facial tissues, the impacts of capital equipment such as buildings, machines, warehouses, and retail outlets were not included, as is often done in LCAs (Madsen, 2007).

This LCA relied on IMPACT 2002+, an impact assessment model which does not calculate the impacts of water use. ReCiPe 2008, used as an alternative impact assessment model to investigate the robustness of the conclusions, also does not address water use in an endpoint category. Paper production can be water intensive, as well as cotton farming. Further study is needed to evaluate the water demands of the products if looking to apply these results in arid locations.

4 Conclusions

The results of this study indicate that switching from disposable facial tissues to reusable cotton handkerchiefs does not result in environmental benefits except under the scenario with the longest time frame (9.375 years) and the largest difference in facial tissue versus handkerchief use. Even this benefit is very small, and would require a commitment to only use handkerchiefs for nearly 10 years – a challenging prospect for most people. Interestingly, the highest impacts for the handkerchief scenarios are not the use phase but the initial manufacturing of the handkerchief. Even after 9 years, the use phase only represents 32% of the climate change impacts for handkerchiefs.

Handkerchiefs, like most inexpensive clothing, are manufactured in China. Ecoinvent recognized the importance of China's contribution to textile manufacturing by integrating most of the electricity needed in the production and processing of fabric to the mix of electricity production typical for China. China depends heavily on coal for electricity, and the impacts of handkerchief production are dominated by coal use, not by cotton growing for most endpoint categories. However, even when the electricity mixes used during manufacturing steps were flipped for handkerchiefs and facial tissues, handkerchiefs still had higher environmental impacts. This suggests that textile production requires high level of electricity, and most of the impacts are due to the overall energy demands versus the exact source of the energy.

Another interesting result of the study is that end-of-life is a relatively insignificant part of the environmental impacts of the products. End-of-life for disposable facial tissues only accounted for 10% or less of the calculated environmental impacts, and disposal of the handkerchiefs and packaging at the end of its useful life represents only 1% or less of calculated environmental damages. Likewise, transportation accounts for a relatively small fraction of impacts (8% or less). Manufacturers can derive the greatest environmental benefit by increasing the energy efficiency of their plants for these products, with the greatest environmental benefits gained by decreasing the electricity used in cotton weaving for handkerchief production.

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6 Appendix

Table A1: Life Cycle Reference Flows for a Single Facial Tissue

Category	*Description of Process/Material*	*Data Source*	*Amount Source*	*Unit*	*Amount for 1 tissue*
Production - Facial Tissue and Packaging					
Tissue	Water, unspecified natural origin/m3	Ecoinvent 2.2	Ecoinvent 2.2 [A]	m^3	1.97E-05
Tissue	Sulphate pulp, average, at regional storage/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	kg	1.32E-03
Tissue	Kaolin, at plant/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	kg	2.67E-05
Tissue	Potato starch, at plant/DE U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	kg	9.29E-06
Tissue	Chemicals inorganic, at plant/GLO U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	kg	4.00E-06
Tissue	Electricity, medium voltage, production NORDEL, at grid/NORDEL U	Ecoinvent 2.2	Eberle & Moller, 2006; Ecoinvent 2.2 [B]	kWh	9.05E-04
Tissue	Electricity, medium voltage, production UCTE, at grid/UCTE U	Ecoinvent 2.2	Eberle & Moller, 2006; Ecoinvent 2.2 [B]	kWh	1.03E-03
Tissue	Light fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	MJ	1.54E-04
Tissue	Natural gas, burned in industrial furnace >100kW/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	MJ	9.97E-03
Tissue	Wood chips, from industry, softwood, burned in furnace 300kW/CH U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	MJ	3.10E-04
Tissue	Transport, freight, rail/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	tkm	2.40E-05
Tissue	Transport, lorry >16t, fleet average/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	tkm	4.00E-06
Tissue	Disposal, sludge from pulp and paper production, 25% water, to sanitary landfill/CH U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	kg	9.98E-06
Tissue	Disposal, ash from paper prod. sludge, 0% water, to residual material landfill/CH U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	kg	2.83E-06
Tissue	Disposal, bilge oil, 90% water, to hazardous waste incineration/CH U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	kg	5.16E-07
Tissue	Disposal, municipal solid waste, 22.9% water, to municipal incineration/CH U	Ecoinvent 2.2	Ecoinvent 2.2 [A]	kg	1.29E-06

Packaging	Packaging, corrugated board, mixed fibre, single wall, at plant/RER U	Ecoinvent 2.2	product specs.	g	2.95E-01
Packaging	Packaging film, LDPE, at plant/RER U	Ecoinvent 2.2	product specs.	g	1.00E-02
Transportation to Retail - Facial Tissue and Packaging					
Shipping	Transport, freight, rail/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [C]	tkm	2.47E-03
Shipping	Transport, lorry >16t, fleet average/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [C]	tkm	1.24E-03
End of Life - Facial Tissue and Packaging					
Landfilling	Disposal, paper, 11.2% water, to municipal incineration/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [D]	g	7.02E-01
Incineration	Disposal, paper, 11.2% water, to sanitary landfill/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [D]	g	8.83E-01
Landfilling	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [D]	g	4.43E-03
Incineration	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [D]	g	5.57E-03

[A] - Derived from the Ecoinvent 2.2 unit process, Kraft paper, beached, at plant/RER U for 1 kg of paper. To derive the impacts for a single facial tissue (1.29 g), the unit processes values were divided by 0.00129. According to a survey by the NRDC, most major facial tissue manufacturers do not use any recycled fibers and is bleached by ECF (Elemental chlorine-free) processing (NRDC, 2009). This unit process is only based on virgin fibers and models the impacts of ECF. All inputs in this unit process were within the range for manufacture of paper towels, a very similar product to facial tissues (Eberle & Moller, 2006).

[B] - Electricity used to produce facial tissue was based on Eberle & Moller (2006), to reflect the higher published level to produce paper towels, which use similar final processing steps (1.5 kWh/kg). Although the leading brand of facial tissue in the U.S. manufactures the product in Ontario, Canada, the proportion of electricity from NORDEL (system operators in Denmark, Finland, Iceland, Norway, and Sweden) and UCTE (grid for Continental Europe) was retained from the Ecoinvent unit process since no electrical mix for Canada existed in Ecoinvent and since the mix of electrical sources across Europe likely models the diversity to electrical production in Canada.

[C] - The leading producer of facial tissue for the U.S. market manufactures facial tissue in Ontario, Canada. There, ship transport was not considered a shipping option for transportation to Northeast U.S. The values for transport on train and truck were retained from the Ecoinvent unit process, Paper, newsprint, at regional storage/RER since the distances were in line with those expected.

[D] - I assumed that the refuse would not be recycled, but would only be either landfilled or incinerated. Based on Van Haaren et al. (2010), in New England, 31% of municipal waste is landfilled, 39% is incinerated, 22% is recycled, and 8% is composted. Since recycling and composting were not considered, landfilling represents 44.29% and incineration accounts for 55.71% of refuse disposal. The mass of the material was multiplied by the fraction intended for landfilling or incineration.

Table A2: Life Cycle Reference Flows for a single handkerchief

Category	*Description of Process/Material*	*Data Source*	*Amount Source*	*Unit*	*Amount for 1 handkerchief*
Production - Handkerchief and Packaging					
handkerchief	Textile, woven cotton, at plant/GLO U	Ecoinvent 2.2	product specs.	g	15.0
handkerchief	Textile refinement, cotton/GLO U	Ecoinvent 2.2	product specs.	g	15.0
handkerchief	Electricity, low voltage, at grid/CN U	Ecoinvent 2.2	Collins & Aumonier, 2002; 2.0 MJ/kg textile cutting and sewing [A]	MJ	2.10E-02
	Electricity, low voltage, at grid/RER U				9.00E-03
packaging	Packaging, corrugated board, mixed fibre, single wall, at plant/RER U	Ecoinvent 2.2	product specs.	g	7.0
packaging	Kraft paper, bleached, at plant/RER U	Ecoinvent 2.2	product specs.	g	1.0
packaging	Packaging film, LDPE, at plant/RER U	Ecoinvent 2.2	product specs.	g	2.3
Transportation to Retail - Handkerchief and Packaging					
Shipping	Transport, transoceanic freight ship/OCE U	Ecoinvent 2.2	Container Transportation, 2011; ship distance Hong Kong to L.A.	tkm	2.99E-01
Shipping	Transport, freight, rail/RER U	Ecoinvent 2.2	Estimated distance from L.A. to Northeast distribution center	tkm	1.01E-01
Shipping	Transport, lorry >16t, fleet average/RER U	Ecoinvent 2.2	Ecoinvent 2.2 [B]	tkm	1.97E-02
Use [C]					
Washing	Tap water, at user/RER U	Ecoinvent 2.2	Haapala et al., 2008; 89.25 L/cycle	kg	1.79E-01
Washing	Soap, at plant/RER U	Ecoinvent 2.2	van Hoof et al., 2003; 78 g	g	1.56E-01

Washing	Electricity, low voltage, at grid/US U	Ecoinvent 2.2	Haapala et al., 2008; 0.544 kWh/cycle	kWh	1.09E-03
Washing	Heat, natural gas, at boiler modulating <100kW/RER U	Ecoinvent 2.2	Bole, 2006; 22.79 MJ/cycle	MJ	4.57E-02
Washing	Polyethylene, HDPE, granulate, at plant/RER U	Ecoinvent 2.2	product specs. [D]	g	1.94E-02
Washing	Injection moulding/RER U	Ecoinvent 2.2	product specs. [D]	g	1.94E-02
Washing	Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	Ecoinvent 2.2	Haapala et al., 2008; 89.25 L/cycle	l	1.79E-01
Washing	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [E]	g	8.58E-03
Washing	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [E]	g	1.08E-02
End of Life - Packaging					
Landfilling	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [E]	g	1.02
Incineration	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [E]	g	1.28
Landfilling	Disposal, packaging cardboard, 19.6% water, to sanitary landfill/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [E]	g	3.10
Incineration	Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [E]	g	3.90
Landfilling	Disposal, packaging paper, 13.7% water, to sanitary landfill/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [E]	g	0.44
Incineration	Disposal, packaging paper, 13.7% water, to municipal incineration/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [E]	g	0.56

[A] - The electricity needed for handkerchief cutting and sewing was derived from Collins & Aumonier (2002) and used the Ecoinvent electricity mix for China (CN) (70%) and Europe (RER) (30%) since the Ecoinvent unit process Textile, woven cotton, at plant/GLO U predominately relies on the same electricity mix. This electricity mix estimates the impact of production in China while still modeling for the possibility that some textile processes are completed in Western countries.

[B] - The value for transport on truck were derived from the Ecoinvent unit process, Paper, newsprint, at regional storage/RER since the distances were in line with those estimated.

[C] - In this table, use values are represented for a single handkerchief. In modeling, it was assumed that all 30 handkerchiefs would be washed when all 30 were soiled along with rest of the individual's laundry. Impacts from laundering were based on the weight fraction of the handkerchiefs (thirty, 15 g handkerchiefs = 450 g) in the average 16.5 pound load of laundry (7,484.4 g) (Bole, 2006). Therefore, the impact of washing 30 handkerchiefs is 6.0125% of the average laundry cycle on a weight basis. Dividing by 30, washing a single handkerchief would account for 0.2% of impacts in an average laundry cycle.

[D] - An empty laundry HDPE bottle weighed 500 g, while the full bottle was 4.535 kg (10 pounds). The amount of laundry detergent for 1 cycle (78 g) represents 1.93% of the total laundry detergent. The impacts of the HDPE bottle manufacture were generated by multiplying the weight of the bottle by the ratio of the bottle used for one cycle (0.0193) and by the ratio of the cycle due to handkerchiefs (0.060125). Finally, to calculate the impact for washing a single handkerchief, the value was divided by 30, the total number of handkerchiefs washed in the cycle.

[E] - I assumed that the refuse would not be recycled, but would only be either landfilled or incinerated. Based on Van Haaren et al. (2010), in New England, 31% of municipal waste is landfilled, 39% is incinerated, 22% is recycled, and 8% is composted. Since recycling and composting were not considered, landfilling represents 44.29% and incineration accounts for 55.71% of refuse disposal. The mass of the material was multiplied by the fraction intended for landfilling or incineration.

Table A3: Max Life Scenario Additions to Reference Flows

Category	*Description of Process/Material*	*Data Source*	*Amount Source*	*Unit*	*Amount for 1 handkerchief*
End of Life - Handkerchief [A]					
Landfilling	Disposal, packaging cardboard, 19.6% water, to sanitary landfill/CH U [B]	Ecoinvent 2.2	Van Haaren et al., 2010 [C]	g	6.64
Incineration	Disposal, textile, soiled, 25% water, to municipal incinerator/CH U	Ecoinvent 2.2	Van Haaren et al., 2010 [C]	g	8.36

[A] - In the Max Life scenarios, the handkerchief is used for its entire useful life and then disposed of. See Table 3 for unit processes on the disposal of the handkerchief packaging.
[B] - Since no unit process for textile landfilling existed in Ecoinvent, the landfilling of a similar product was chosen to estimate the environmental impacts.
[C] - I assumed that the refuse would not be recycled, but would only be either landfilled or incinerated. Based on Van Haaren et al. (2010), in New England, 31% of municipal waste is landfilled, 39% is incinerated, 22% is recycled, and 8% is composted. Since recycling and composting were not considered, landfilling represents 44.29% and incineration accounts for 55.71% of refuse disposal. The mass of the material was multiplied by the fraction intended for landfilling or incineration.

Table A4: Electricity Mix Sensitivity Analysis Alterations to Reference Flows

Scenario	*Original Description of Process*	*Unit Process Location*	*Amended Description of Process*	*Altered Electricity Mix*	*Amount*
Production - Handkerchief [A]					
Handkerchief RER	Weeving, cotton/GLO U	subprocess of Textile, woven cotton, at plant/GLO U	Weeving, cotton/RER	Electricity, low voltage, production NORDEL, at grid/NORDEL U Electricity, low voltage. Production UCTE, at grid/UCTE U	4.7269 kWh/kg 5.3842 kWh/kg
Handkerchief RER	Yarn production, cotton fibres/GLO U	subprocess of Yarn, cotton, at plant/GLO U, which is a subprocess of Textile, woven cotton, at plant/GLO U	Yarn production, cotton fibres/RER	Electricity, low voltage, production NORDEL, at grid/NORDEL U Electricity, low voltage. Production UCTE, at grid/UCTE U	3.97375 kWh/kg 4.52625 kWh/kg
Handkerchief RER	Textile refinement, cotton/GLO U	-	Textile refinement, cotton/RER	Electricity, low voltage, production NORDEL, at grid/NORDEL U Electricity, low voltage. Production UCTE, at grid/UCTE U	0.5185 kWh/kg 0.5906 kWh/kg
Handkerchief RER	(Cutting & Sewing) Electricity, low voltage, at grid/CN U Electricity, low voltage, at grid/RER U	-	Electricity, low voltage, production NORDEL, at grid/NORDEL U Electricity, low voltage. Production UCTE, at grid/UCTE U	Electricity, low voltage, production NORDEL, at grid/NORDEL U Electricity, low voltage. Production UCTE, at grid/UCTE U	0.935 MJ/kg 1.065 MJ/kg

Production - Facial Tissue [B]					
Facial Tissue GLO	(Tissue Paper Production) Electricity, medium voltage, production NORDEL, at grid/NORDEL U Electricity, medium voltage, production UCTE, at grid/UCTE U	-	Electricity, medium voltage, at grid/CN U Electricity, medium voltage, production RER, at grid/RER U	Electricity, medium voltage, at grid/CN U Electricity, medium voltage, production RER, at grid/RER U	1.05 KWh/kg 0.45 kWh/kg
Facial Tissue GLO	Sulphate Pulp, ECF bleached, at plant/RER U	subprocess of Sulphate pulp, average, at regional storage/RER U	Sulphate Pulp, ECF bleached, at plant/GLO	Electricity, medium voltage, at grid/CN U Electricity, medium voltage, production RER, at grid/RER U	0.049 kWh/kg 0.021 kWh/kg
Facial Tissue GLO	Sulphate Pulp, TCF bleached, at plant/RER U	subprocess of Sulphate pulp, average, at regional storage/RER U	Sulphate Pulp, TCF bleached, at plant/GLO	Electricity, medium voltage, at grid/CN U Electricity, medium voltage, production RER, at grid/RER U	0.07 kWh/kg 0.03 kWh/kg
Facial Tissue GLO	Sulphate Pulp, unbleached, at plant/RER U	subprocess of Sulphate pulp, average, at regional storage/RER U	Sulphate Pulp, unbleached, at plant/GLO	Electricity, medium voltage, at grid/CN U Electricity, medium voltage, production RER, at grid/RER U	0.2912 kWh/kg 0.1248 kWh/kg

[A] - Electricity used in key processes to produce a handkerchief was altered. Ancillary processes, such as the electricity needed to produce sodium chloride used in textile refinement, were not altered. Electricity mix was altered to reflect the percentage used in the facial tissue functional unit scenario (46.75% NORDEL (system operators in Denmark, Finland, Iceland, Norway, and Sweden), 53.25% UCTE (grid operators in continental Europe)).

[B] - Electricity used in key processes to produce a facial tissue was altered. Ancillary processes, such as the electricity needed to produce potato starch used as an additive in paper production, was not altered. Electricity mix was altered to reflect the percentages used in the handkerchief functional unit scenario (70% China (CN), 30% Europe (RER)).

Table A5: Midpoint Impact LCIA Categories for the Functional Unit

IMPACT 2002+ Midpoint Category	*Unit*	*Functional Unit*	
		Handkerchief	*Facial Tissue*
Carcinogens	kg C_2H_3Cl eq	0.220	0.033
Non-carcinogens	kg C_2H_3Cl eq	0.595	0.102
Respiratory inorganics	kg PM2.5 eq	0.019	0.002
Ionizing radiation	Bq C-14 eq	181	90.6
Ozone layer depletion	kg CFC-11 eq	7.6E-07	2.3E-07
Respiratory organics	kg C_2H_4 eq	0.002	0.001
Aquatic ecotoxicity	kg TEG water	1643	115
Terrestrial ecotoxicity	kg TEG soil	225	34.8
Terrestrial acid/nutri	kg SO_2 eq	0.448	0.053
Land occupation	m^2org.arable	5.13	1.16
Aquatic acidification	kg SO_2 eq	0.132	0.012
Aquatic eutrophication	kg PO_4 P-lim	0.006	0.001
Global warming	kg CO_2 eq	15.9	2.41
Non-renewable energy	MJ primary	210	41.4
Mineral extraction	MJ surplus	0.003	0.001

Table A6: Reference Flows Life Cycle Impact Assessment Results for Handkerchief Functional Unit

Category	Description of Process/Material	Climate Change (kg CO_2-eq)	Human Health (DALY)	Ecosystem Quality (PDF*m^2*y)	Resources (MJ)	Reference Flow Amount	Unit
Production - Handkerchief and Packaging	**Total**	**13.6**	**1.47E-05**	**7.27**	**170**		
handkerchief	Textile, woven cotton, at plant/GLO U	10.7	1.30E-05	6.16	123	450	g
handkerchief	Textile refinement, cotton/GLO U	2.15	1.09E-06	0.906	33.1	450	g
handkerchief	Electricity, low voltage, at grid/CN U	0.237	2.95E-07	0.011	2.27	0.63	MJ
handkerchief	Electricity, low voltage, at grid/RER U	0.040	2.14E-08	0.003	0.836	0.27	MJ
packaging	Packaging, corrugated board, mixed fibre, single wall, at plant/RER U	0.216	1.30E-07	0.146	3.59	210	g
packaging	Kraft paper, bleached, at plant/RER U	0.045	4.40E-08	0.041	0.846	30	g
packaging	Packaging film, LDPE, at plant/RER U	0.167	9.71E-08	0.006	6.27	69	g
Transportation to Retail - Handkerchief and Packaging	**Total**	**0.225**	**3.45E-07**	**0.039**	**3.70**		
Shipping	Transport, transoceanic freight ship/OCE U	0.078	2.01E-07	0.011	1.17	8.96	tkm
Shipping	Transport, freight, rail/RER U	0.085	7.60E-08	0.006	1.63	3.04	tkm
Shipping	Transport, lorry >16t, fleet average/RER U	0.061	6.83E-08	0.022	0.896	0.590	tkm
Use	**Total**	**2.00**	**7.06E-07**	**0.605**	**36.3**		
Washing	Tap water, at user/RER U	0.019	1.12E-08	0.020	0.384	80.3	kg
Washing	Soap, at plant/RER U	0.102	1.64E-07	0.090	0.960	70.2	g
Washing	Electricity, low voltage, at grid/US U	0.391	2.96E-07	0.035	6.47	0.489	kWh
Washing	Heat, natural gas, at boiler modulating <100kW/RER U	1.44	1.64E-07	0.007	27.4	20.5	MJ
Washing	Polyethylene, HDPE, granulate, at plant/RER U	0.015	1.30E-08	2.10E-04	0.677	8.70	g
Washing	Injection moulding/RER U	0.011	5.00E-09	0.001	0.232	8.70	g
Washing	Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	0.008	5.18E-08	0.452	0.182	80.3	l
Washing	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	2.25E-04	3.38E-11	1.48E-06	2.97E-04	3.85	g
Washing	Disposal, polyethylene, 0.4% water, to municipal	0.015	1.44E-09	1.80E-05	7.84E-04	4.84	g

	incineration/CH U						
End of Life - Packaging	**Total**	**0.162**	**5.30E-08**	**1.16E-03**	**0.067**		
Landfilling	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	0.002	2.68E-10	1.17E-05	0.002	30.6	g
Incineration	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	0.115	1.14E-08	1.43E-04	0.006	38.4	g
Landfilling	Disposal, packaging cardboard, 19.6% water, to sanitary landfill/CH U	0.039	2.14E-09	9.40E-05	0.018	93.0	g
Incineration	Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH U	0.002	3.37E-08	4.69E-04	0.035	117	g
Landfilling	Disposal, packaging paper, 13.7% water, to sanitary landfill/CH U	0.004	3.08E-10	4.25E-05	0.003	13.3	g
Incineration	Disposal, packaging paper, 13.7% water, to municipal incineration/CH U	2.84E-04	5.16E-09	4.02E-04	0.004	16.7	g
Handkerchief Functional Unit Total	**Total**	***15.9***	***1.58E-05***	***7.92***	***210***		

Table A7: Reference Flows Life Cycle Impact Assessment Results for Facial Tissue Functional Unit

Category	*Description of Process/Material*	*Climate Change ($kg\ CO_2$-eq)*	*Human Health (DALY)*	*Ecosystem Quality ($PDF*m^2*y$)*	*Resources (MJ)*	*Reference Flow Amount*	*Unit*
Production - Facial Tissue and Packaging	**Total**	**2.00**	**1.78E-06**	**1.55**	**38.6**		
Tissue	Sulphate pulp, average, at regional storage/RER U	0.685	1.22E-06	1.28	11.4	1.03	kg
Tissue	Kaolin, at plant/RER U	0.004	1.45E-09	2.51E-04	0.079	0.021	kg
Tissue	Potato starch, at plant/DE U	0.003	7.80E-09	0.040	0.045	0.007	kg
Tissue	Chemicals inorganic, at plant/GLO U	0.005	3.73E-09	3.77E-04	0.077	0.003	kg
Tissue	Electricity, medium voltage, production NORDEL, at grid/NORDEL U	0.110	9.34E-08	0.030	3.75	0.710	kWh
Tissue	Electricity, medium voltage, production UCTE, at grid/UCTE U	0.412	2.24E-07	0.024	8.61	0.809	kWh
Tissue	Light fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	0.010	2.22E-09	0.002	0.151	0.121	MJ
Tissue	Natural gas, burned in industrial furnace >100kW/RER U	0.510	5.37E-08	0.002	9.74	7.83	MJ
Tissue	Wood chips, from industry, softwood, burned in furnace 300kW/CH U	0.001	1.15E-08	0.008	0.015	0.243	MJ
Tissue	Transport, freight, rail/RER U	5.29E-04	4.71E-10	3.70E-05	0.010	0.019	tkm
Tissue	Transport, lorry >16t, fleet average/RER U	3.26E-04	3.64E-10	1.16E-04	0.005	0.003	tkm
Tissue	Disposal, sludge from pulp and paper production, 25% water, to sanitary landfill/CH U	0.002	5.56E-10	6.38E-05	0.011	0.008	kg
Tissue	Disposal, ash from paper prod. sludge, 0% water, to residual material landfill/CH U	6.27E-06	7.33E-10	1.13E-05	9.52E-05	0.002	kg
Tissue	Disposal, bilge oil, 90% water, to hazardous waste incineration/CH U	0.001	1.96E-10	9.52E-06	0.011	4.05E-04	kg
Tissue	Disposal, municipal solid waste, 22.9% water, to municipal incineration/CH U	5.03E-04	2.98E-10	1.77E-05	3.15E-04	0.001	kg
Packaging	Packaging, corrugated board, mixed fibre, single wall, at plant/RER U	0.238	1.44E-07	0.161	3.96	232	g

Packaging	Packaging film, LDPE, at plant/RER U		0.019	1.11E-08	6.68E-04	0.713	7.85	g
Transportation to Retail - Facial Tissue and Packaging		**Total**	**0.156**	**1.62E-07**	**0.040**	**2.52**		
Shipping	Transport, freight, rail/RER U		0.055	4.86E-08	0.004	1.04	1.94	tkm
Shipping	Transport, lorry >16t, fleet average/RER U		0.101	1.13E-07	0.036	1.48	0.973	tkm
End of Life - Facial Tissue and Packaging		**Total**	**0.248**	**1.84E-07**	**1.54E-02**	**0.261**		
Landfilling	Disposal, paper, 11.2% water, to municipal incineration/CH U		0.009	1.67E-07	1.32E-02	0.115	551	g
Incineration	Disposal, paper, 11.2% water, to sanitary landfill/CH U		0.226	1.56E-08	0.002	0.145	693	g
Landfilling	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U		2.03E-04	3.05E-11	1.33E-06	2.68E-04	3.48	g
Incineration	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U		0.013	1.30E-09	1.62E-05	7.07E-04	4.37	g
Facial Tissue Functional Unit Total		**Total**	***2.41***	***2.12E-06***	***1.60***	***41.36***		

Table A8: Handkerchief Unit Processes that Give the Largest % Contribution

Category	*Description of Process/Material*	*Damage Assessment Amount*	*Unit*	*% of Total*
Climate Change	**Total**	**15.9**	**kg CO2 eq**	**100.0%**
	Remaining Processes	*3.97*	*kg CO2 eq*	*24.9%*
Coal		***8.77***	***kg CO2 eq***	***55.0%***
	Hard coal, burned in power plant/CN U	6.02	kg CO2 eq	37.8%
	Hard coal, at mine/CN U	1.55	kg CO2 eq	9.7%
	Hard coal, burned in power plant/RFC U	0.42	kg CO2 eq	2.6%
	Hard coal, burned in power plant/SERC U	0.39	kg CO2 eq	2.5%
	Hard coal, burned in coal mine power plant/CN U	0.20	kg CO2 eq	1.3%
	Lignite, burned in power plant/DE U	0.19	kg CO2 eq	1.2%
Natural Gas		***1.63***	***kg CO2 eq***	***10.2%***
	Natural gas, burned in boiler modulating <100kW/RER U	1.20	kg CO2 eq	7.5%
	Natural gas, burned in power plant/US U	0.22	kg CO2 eq	1.4%
	Natural gas, burned in industrial furnace >100kW/RER U	0.21	kg CO2 eq	1.3%
Fuel Oil		***1.32***	***kg CO2 eq***	***8.3%***
	Light fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	1.08	kg CO2 eq	6.8%
	Heavy fuel oil, burned in power plant/CZ U	0.24	kg CO2 eq	1.5%
Cotton		***0.24***	***kg CO2 eq***	***1.5%***
	Cotton fibres, ginned, at farm/CN U	0.24	kg CO2 eq	1.5%
Human Health	**Total**	**1.58E-05**	**DALY**	**100.0%**
	Remaining Processes	*3.47E-06*	*DALY*	*22.0%*
Coal		***1.02E-05***	***DALY***	***64.9%***
	Hard coal, burned in power plant/CN U	6.89E-06	DALY	43.7%
	Hard coal, burned in coal mine power plant/CN U	1.70E-06	DALY	10.8%
	Disposal, hard coal ash, 0% water, to residual material landfill/PL U	7.40E-07	DALY	4.7%
	Hard coal, at mine/CN U	5.03E-07	DALY	3.2%

	Hard coal, burned in power plant/RFC U	2.26E-07	DALY	1.4%
	Hard coal, burned in power plant/SERC U	1.76E-07	DALY	1.1%
Cotton		***1.37E-06***	***DALY***	***8.7%***
	Cotton fibres, at farm/US U	7.68E-07	DALY	4.9%
	Cotton fibres, ginned, at farm/CN U	6.06E-07	DALY	3.8%
Natural Gas		***4.27E-07***	***DALY***	***2.7%***
	Natural gas, at production/RNA U	4.27E-07	DALY	2.7%
Shipping		***2.74E-07***	***DALY***	***1.7%***
	Operation, transoceanic freight ship/OCE U	2.74E-07	DALY	1.7%
Ecosystem Quality	**Total**	**7.92**	**PDF*m2*yr**	**100.0%**
	Remaining Processes	*0.754*	*PDF*m2*yr*	*9.5%*
Cotton		***5.338***	***PDF*m2*yr***	***67.4%***
	Cotton fibres, ginned, at farm/CN U	3.41	PDF*m2*yr	43.1%
	Cotton fibres, at farm/US U	1.75	PDF*m2*yr	22.2%
	Application of plant protection products, by field sprayer/CH U	0.173	PDF*m2*yr	2.2%
Sewage Treatment		***1.09***	***PDF*m2*yr***	***13.7%***
	Treatment, sewage, to wastewater treatment, class 5/CH U	0.636	PDF*m2*yr	8.0%
	Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	0.452	PDF*m2*yr	5.7%
Coal		***0.421***	***PDF*m2*yr***	***5.3%***
	Hard coal, burned in power plant/CN U	0.272	PDF*m2*yr	3.4%
	Blasting/RER U	0.149	PDF*m2*yr	1.9%
Fuel Oil		***0.184***	***PDF*m2*yr***	***2.3%***
	Light fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	0.184	PDF*m2*yr	2.3%
Vegetable Oil for Soap		***0.135***	***PDF*m2*yr***	***1.7%***
	Husked nuts harvesting, at farm/PH U	0.135	PDF*m2*yr	1.7%
Resources	**Total**	**210**	**MJ primary**	**100.0%**
	Remaining Processes	*14.6*	*MJ primary*	*7.0%*
Coal		***89.5***	***MJ primary***	***42.7%***
	Hard coal, at mine/CN U	70.9	MJ primary	33.8%

	Hard coal, at mine/RNA U	13.8	MJ primary	6.6%
	Lignite, at mine/RER U	4.86	MJ primary	2.3%
Natural Gas		***47.1***	***MJ primary***	***22.5%***
	Natural gas, at production onshore/RU U	15.6	MJ primary	7.4%
	Natural gas, at production onshore/NL U	7.00	MJ primary	3.3%
	Natural gas, at production offshore/NO U	6.57	MJ primary	3.1%
	Natural gas, unprocessed, at extraction/RNA U	5.05	MJ primary	2.4%
	Natural gas, at production onshore/DZ U	4.07	MJ primary	1.9%
	Natural gas, at production onshore/DE U	3.63	MJ primary	1.7%
	Natural gas, at production offshore/NL U	2.91	MJ primary	1.4%
	Natural gas, at production offshore/GB U	2.30	MJ primary	1.1%
Oil		***31.90***	***MJ primary***	***15.2%***
	Crude oil, at production onshore/RME U	8.49	MJ primary	4.1%
	Crude oil, at production offshore/NO U	7.08	MJ primary	3.4%
	Crude oil, at production onshore/RU U	5.91	MJ primary	2.8%
	Crude oil, at production offshore/GB U	5.89	MJ primary	2.8%
	Crude oil, at production onshore/RAF U	4.52	MJ primary	2.2%
Uranium		**20.85**	***MJ primary***	***9.9%***
	Uranium natural, at underground mine/RNA U	12.5	MJ primary	6.0%
	Uranium natural, at open pit mine/RNA U	8.34	MJ primary	4.0%
Plastic		***5.62***	***MJ primary***	***2.7%***
	Polyethylene, LDPE, granulate, at plant/RER U	5.62	MJ primary	2.7%

Based on the Handkerchief Functional Unit with a 1% cutoff. Remaining Processes are the sum of all other unit processes contributing less than 1% to the Damage Assessment score.

Table A9: Facial Tissue Unit Processes that Give the Largest % Contribution

Category	*Description of Process/Material*	*Damage Assessment Amount*	*Unit*	*% of Total*
Climate Change	**Total**	**2.41**	**kg CO2 eq**	**100.0%**
	Remaining Processes	*0.659*	*kg CO2 eq*	*27.4%*
Natural Gas		***0.559***	***kg CO2 eq***	***23.2%***
	Natural gas, burned in industrial furnace >100kW/RER U	0.452	kg CO2 eq	18.8%
	Natural gas, burned in power plant/IT U	0.041	kg CO2 eq	1.7%
	Natural gas, burned in gas turbine, for compressor station/RU U	0.039	kg CO2 eq	1.6%
	Blast furnace gas, burned in power plant/RER U	0.027	kg CO2 eq	1.1%
Coal		***0.400***	***kg CO2 eq***	***16.6%***
	Lignite, burned in power plant/DE U	0.104	kg CO2 eq	4.3%
	Hard coal, burned in power plant/DE U	0.073	kg CO2 eq	3.0%
	Hard coal, burned in power plant/NORDEL U	0.061	kg CO2 eq	2.5%
	Hard coal, burned in power plant/PL U	0.049	kg CO2 eq	2.0%
	Lignite, burned in power plant/PL U	0.041	kg CO2 eq	1.7%
	Hard coal, burned in power plant/ES U	0.037	kg CO2 eq	1.6%
	Lignite, burned in power plant/CZ U	0.035	kg CO2 eq	1.4%
Shipping		***0.309***	***kg CO2 eq***	***12.9%***
	Operation, lorry >16t, fleet average/RER U	0.243	kg CO2 eq	10.1%
	Operation, freight train/RER U	0.039	kg CO2 eq	1.6%
	Operation, transoceanic freight ship/OCE U	0.027	kg CO2 eq	1.1%
Landfilling		***0.221***	***kg CO2 eq***	***9.2%***
	Disposal, paper, 11.2% water, to sanitary landfill/CH U	0.221	kg CO2 eq	9.2%
Pulp		***0.141***	***kg CO2 eq***	***5.9%***
	Sulphate pulp, ECF bleached, at plant/RER U	0.141	kg CO2 eq	5.9%
Cardboard		***0.089***	***kg CO2 eq***	***3.7%***
	Corrugated board base paper, wellenstoff, at plant/RER U	0.052	kg CO2 eq	2.2%

	Corrugated board base paper, testliner, at plant/RER U	0.036	kg CO2 eq	1.5%
Diesel		***0.028***	***kg CO2 eq***	***1.1%***
	Diesel, burned in building machine/GLO U	0.028	kg CO2 eq	1.1%
Human Health	**Total**	**2.12E-06**	**DALY**	**100.0%**
	Remaining Processes	*5.43E-07*	*DALY*	*25.6%*
Pulp		***6.84E-07***	***DALY***	***32.2%***
	Sulphate pulp, ECF bleached, at plant/RER U	5.16E-07	DALY	24.3%
	Sulphate pulp, TCF bleached, at plant/RER U	1.11E-07	DALY	5.2%
	Sulphate pulp, unbleached, at plant/RER U	5.67E-08	DALY	2.7%
Shipping		***4.23E-07***	***DALY***	***19.9%***
	Operation, lorry >16t, fleet average/RER U	2.79E-07	DALY	13.1%
	Operation, transoceanic freight ship/OCE U	7.34E-08	DALY	3.5%
	Operation, freight train/RER U	7.11E-08	DALY	3.3%
Incineration		***1.69E-07***	***DALY***	***7.9%***
	Process-specific burdens, municipal waste incineration/CH U	1.45E-07	DALY	6.8%
	Disposal, paper, 11.2% water, to municipal incineration/CH U	2.40E-08	DALY	1.1%
Coal		***1.32E-07***	***DALY***	***6.2%***
	Hard coal, burned in power plant/ES U	4.14E-08	DALY	2.0%
	Lignite, burned in power plant/CS U	3.73E-08	DALY	1.8%
	Hard coal, burned in power plant/PL U	2.84E-08	DALY	1.3%
	Lignite, burned in power plant/PL U	2.53E-08	DALY	1.2%
Electricity from wood		***8.08E-08***	***DALY***	***3.8%***
	Electricity, at cogen ORC 1400kWth, wood, allocation exergy/CH U	8.08E-08	DALY	3.8%
Diesel		***5.97E-08***	***DALY***	***2.8%***
	Diesel, burned in building machine/GLO U	5.97E-08	DALY	2.8%
Cardboard		***3.26E-08***	***DALY***	***1.5%***
	Corrugated board base paper, kraftliner, at plant/RER U	3.26E-08	DALY	1.5%
Ecosystem Quality	**Total**	**1.61**	**PDF*m2*yr**	**100.0%**
	Remaining Processes	*0.124*	*PDF*m2*yr*	*7.7%*

Wood		***1.226***	***PDF*m2*yr***	***76.3%***
	Softwood, Scandinavian, standing, under bark, in forest/NORDEL U	0.607	PDF*m2*yr	37.8%
	Hardwood, Scandinavian, standing, under bark, in forest/NORDEL U	0.396	PDF*m2*yr	24.6%
	Industrial wood, Scandinavian softwood, under bark, u=140%, at forest road/NORDEL U	0.074	PDF*m2*yr	4.6%
	Hardwood, standing, under bark, in forest/RER U	0.053	PDF*m2*yr	3.3%
	Industrial wood, Scandinavian hardwood, under bark, u=80%, at forest road/NORDEL U	0.050	PDF*m2*yr	3.1%
	Softwood, standing, under bark, in forest/RER U	0.046	PDF*m2*yr	2.9%
Starch		***0.106***	***PDF*m2*yr***	***6.6%***
	Potatoes IP, at farm/CH U	0.086	PDF*m2*yr	5.4%
	Green manure IP, until march/CH U	0.019	PDF*m2*yr	1.2%
Shipping		***0.098***	***PDF*m2*yr***	***6.1%***
	Operation, lorry >16t, fleet average/RER U	0.098	PDF*m2*yr	6.1%
Electricity from wood		***0.033***	***PDF*m2*yr***	***2.1%***
	Disposal, wood ash mixture, pure, 0% water, to landfarming/CH U	0.033	PDF*m2*yr	2.1%
Pulp		***0.020***	***PDF*m2*yr***	***1.2%***
	Sulphate pulp, ECF bleached, at plant/RER U	0.020	PDF*m2*yr	1.2%
Resources	**Total**	**41.4**	**MJ primary**	**100.0%**
	Remaining Processes	*1.71*	*MJ primary*	*4.1%*
Natural gas		***16.32***	***MJ primary***	***39.4%***
	Natural gas, at production onshore/RU U	5.83	MJ primary	14.1%
	Natural gas, at production offshore/NO U	2.78	MJ primary	6.7%
	Natural gas, at production onshore/DZ U	2.77	MJ primary	6.7%
	Natural gas, at production onshore/NL U	2.47	MJ primary	6.0%
	Natural gas, at production offshore/NL U	1.03	MJ primary	2.5%
	Natural gas, at production onshore/DE U	0.935	MJ primary	2.3%
	Natural gas, at production offshore/GB U	0.530	MJ primary	1.3%
Uranium		***8.815***	***MJ primary***	***21.3%***
	Uranium natural, at underground mine/RNA U	5.29	MJ primary	12.8%
	Uranium natural, at open pit mine/RNA U	3.53	MJ primary	8.5%

Oil		***7.965***	***MJ primary***	***19.2%***
	Crude oil, at production onshore/RME U	1.81	MJ primary	4.4%
	Crude oil, at production onshore/RAF U	1.53	MJ primary	3.7%
	Crude oil, at production offshore/NO U	1.44	MJ primary	3.5%
	Crude oil, at production onshore/RU U	1.20	MJ primary	2.9%
	Crude oil, at production offshore/GB U	1.20	MJ primary	2.9%
	Crude oil, at production/NG U	0.786	MJ primary	1.9%
Coal		***5.94***	***MJ primary***	***14.4%***
	Lignite, at mine/RER U	2.79	MJ primary	6.7%
	Hard coal, at mine/WEU U	1.73	MJ primary	4.2%
	Hard coal, at mine/EEU U	0.987	MJ primary	2.4%
	Hard coal, at mine/ZA U	0.437	MJ primary	1.1%
Plastic		***0.639***	***MJ primary***	***1.5%***
	Polyethylene, LDPE, granulate, at plant/RER U	0.639	MJ primary	1.5%

Based on the Facial Tissue Functional Unit with a 1% cutoff. Remaining Processes are the sum of all other unit processes contributing less than 1% to the Damage Assessment score.

Table A10: Use Scenarios Impact Assessment Results

Scenarios	Product	Climate Change ($kg\ CO_2$-eq)	Human Health (DALY)	Ecosystem Quality ($PDF*m^2*y$)	Resources (MJ)
Duration: 1 yr					
Min Cold & Max Base Use	handkerchief	15.6	1.57E-05	7.82	204
	tissue	1.39	1.23E-06	0.929	23.9
No Cold & Max Base Use	handkerchief	15.6	1.57E-05	7.81	203
	tissue	1.12	9.88E-07	0.747	19.3
Max Cold & Min Base Use	handkerchief	14.6	1.53E-05	7.53	186
	tissue	2.41	2.12E-06	1.61	41.4
Min Cold & Min Base Use	handkerchief	14.3	1.52E-05	7.42	179
	tissue	1.39	1.23E-06	0.929	23.9
No Cold & Min Base Use	handkerchief	14.2	1.52E-05	7.39	177
	tissue	1.12	9.88E-07	0.747	19.3
Duration: 3.34 yrs					
Max Life Max Cold & Max Base Use	handkerchief	20.7	1.76E-05	9.34	295
	tissue	8.04	7.09E-06	5.37	138
Duration: 9.375 yrs					
Max Life Max Cold & Min Base Use	handkerchief	20.7	1.76E-05	9.34	295
	tissue	22.6	1.99E-05	15.1	388

Table A11: Reference Flows Life Cycle Impact Assessment Results for Electricity Mix Scenario Handkerchief RER

Category	*Description of Process/Material*	*Climate Change (kg CO_2-eq)*	*Human Health (DALY)*	*Ecosystem Quality (PDF*m^2*y)*	*Resources (MJ)*
Production - Handkerchief and Packaging	**Total**	**6.73**	**5.22E-06**	**7.10**	**136**
handkerchief	Textile, woven cotton, at plant/GLO U [A]	4.44	4.31E-06	6.00	91.1
handkerchief	Textile refinement, cotton/GLO U [A]	1.77	5.75E-07	0.900	31.5
handkerchief	Electricity, low voltage, production NORDEL, at grid/NORDEL U [A]	0.020	1.68E-08	0.005	0.676
handkerchief	Electricity, low voltage, production UCTE, at grid/UCTE U [A]	0.075	4.09E-08	0.004	1.58
packaging	Packaging, corrugated board, mixed fibre, single wall, at plant/RER U	0.216	1.30E-07	0.146	3.59
packaging	Kraft paper, bleached, at plant/RER U	0.045	4.40E-08	0.040	0.846
packaging	Packaging film, LDPE, at plant/RER U	0.167	9.71E-08	0.006	6.27
Transportation to Retail - Handkerchief and Packaging	**Total**	**0.225**	**3.45E-07**	**0.039**	**3.69**
Shipping	Transport, transoceanic freight ship/OCE U	0.078	2.01E-07	0.011	1.17
Shipping	Transport, freight, rail/RER U	0.085	7.60E-08	0.006	1.63
Shipping	Transport, lorry >16t, fleet average/RER U	0.061	6.83E-08	0.022	0.896
Use	**Total**	**2.00**	**7.07E-07**	**0.605**	**36.3**
Washing	Tap water, at user/RER U	0.019	1.12E-08	0.020	0.384
Washing	Soap, at plant/RER U	0.102	1.64E-07	0.090	0.960
Washing	Electricity, low voltage, at grid/US U	0.391	2.96E-07	0.035	6.47
Washing	Heat, natural gas, at boiler modulating <100kW/RER U	1.44	1.64E-07	0.007	27.4
Washing	Polyethylene, HDPE, granulate, at plant/RER U	0.015	1.30E-08	2.10E-04	0.677
Washing	Injection moulding/RER U	0.011	5.00E-09	0.001	0.232
Washing	Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	0.008	5.18E-08	0.452	0.182
Washing	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	2.25E-04	3.38E-11	1.48E-06	2.97E-04
Washing	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	0.014	1.44E-09	1.80E-05	7.84E-04
End of Life - Handkerchief and Packaging	**Total**	**0.162**	**5.30E-08**	**1.16E-03**	**0.067**
Landfilling	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	0.002	2.68E-10	1.17E-05	0.002

Incineration	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	0.115	1.14E-08	1.43E-04	0.006
Landfilling	Disposal, packaging cardboard, 19.6% water, to sanitary landfill/CH U	0.039	2.14E-09	9.40E-05	0.018
Incineration	Disposal, packaging cardboard, 19.6% water, to municipal incineration/CH U	0.002	3.37E-08	4.69E-04	0.034
Landfilling	Disposal, packaging paper, 13.7% water, to sanitary landfill/CH U	0.004	3.08E-10	4.25E-05	0.003
Incineration	Disposal, packaging paper, 13.7% water, to municipal incineration/CH U	2.84E-04	5.16E-09	4.02E-04	0.004
Handkerchief RER Scenario Total	**Total**	***9.1***	***6.32E-06***	***7.75***	***176***

[A] - The country of origin and percentage mix of electricity in these core production processes were altered to match the electricity sources used to model facial tissue production for the functional unit. Since the facial tissue functional unit relied on two European (RER) sources of electricity, NORDEL and UCTE, the Handkerchief RER scenario also relies on these electricity sources in the same proportions. Electricity sources was only altered for core production processes - not ancillary processes such as the production of sodium chloride used in textile refinement or the production of packaging materials.

Table A12: Reference Flows Life Cycle Impact Assessment Results for Facial Tissue GLO

Category	*Description of Process/Material*	*Climate Change (kg CO_2-eq)*	*Human Health (DALY)*	*Ecosystem Quality (PDF*m^2*y)*	*Resources (MJ)*
Production - Facial Tissue and Packaging	**Total**	**2.89**	**3.06E-06**	**1.56**	**42.0**
Tissue	Sulphate pulp, average, at regional storage/RER U [A]	0.740	1.30E-06	1.28	11.7
Tissue	Kaolin, at plant/RER U	0.004	1.45E-09	2.51E-04	0.079
Tissue	Potato starch, at plant/DE U	0.003	7.80E-09	0.040	0.045
Tissue	Chemicals inorganic, at plant/GLO U	0.005	3.73E-09	3.77E-04	0.077
Tissue	Electricity, medium voltage, at grid/CN U [A]	1.13	1.41E-06	0.050	10.9
Tissue	Electricity, medium voltage, production RER, at grid/RER U [A]	0.219	1.17E-07	0.015	4.57
Tissue	Light fuel oil, burned in industrial furnace 1MW, non-modulating/RER U	0.010	2.22E-09	0.002	0.151
Tissue	Natural gas, burned in industrial furnace >100kW/RER U	0.510	5.37E-08	0.002	9.74
Tissue	Wood chips, from industry, softwood, burned in furnace 300kW/CH U	5.00E-04	1.15E-08	0.008	0.014
Tissue	Transport, freight, rail/RER U	0.001	4.71E-10	3.70E-05	0.010
Tissue	Transport, lorry >16t, fleet average/RER U	3.26E-04	3.64E-10	1.16E-04	0.005
Tissue	Disposal, sludge from pulp and paper production, 25% water, to sanitary landfill/CH U	0.002	5.56E-10	6.38E-05	0.011
Tissue	Disposal, ash from paper prod. sludge, 0% water, to residual material landfill/CH U	6.27E-06	7.33E-10	1.13E-05	9.52E-05
Tissue	Disposal, bilge oil, 90% water, to hazardous waste incineration/CH U	8.63E-04	1.96E-10	9.52E-06	0.011
Tissue	Disposal, municipal solid waste, 22.9% water, to municipal incineration/CH U	5.03E-04	2.98E-10	1.77E-05	3.15E-04
Packaging	Packaging, corrugated board, mixed fibre, single wall, at plant/RER U	0.238	1.44E-07	0.161	3.96
Packaging	Packaging film, LDPE, at plant/RER U	0.019	1.11E-08	6.68E-04	0.713
Transportation to Retail - Facial Tissue and Packaging	**Total**	**0.155**	**1.61E-07**	**0.040**	**2.52**
Shipping	Transport, freight, rail/RER U	0.054	4.86E-08	0.004	1.04
Shipping	Transport, lorry >16t, fleet average/RER U	0.101	1.13E-07	0.036	1.48
End of Life - Facial Tissue and Packaging	**Total**	**0.248**	**1.84E-07**	**0.015**	**0.261**

Incineration	Disposal, paper, 11.2% water, to municipal incineration/CH U	0.009	1.67E-07	0.013	0.115
Landfilling	Disposal, paper, 11.2% water, to sanitary landfill/CH U	0.226	1.56E-08	0.002	0.145
Landfilling	Disposal, polyethylene, 0.4% water, to sanitary landfill/CH U	0.000	3.05E-11	1.33E-06	2.68E-04
Incineration	Disposal, polyethylene, 0.4% water, to municipal incineration/CH U	0.013	1.30E-09	1.62E-05	7.07E-04
Facial Tissue GLO Scenario Total	**Total**	***3.29***	***3.41E-06***	***1.62***	***44.7***

[A] - The country of origin and percentage mix of electricity in these core production processes were altered to match the global (GLO) electricity sources used to model handkerchief production for the functional unit. Since the facial tissue functional unit relied on Chinese (CN) and European (RER) electricity mixes, the Facial Tissue GLO scenario also relies on these electricity sources in the same proportions. Electricity sources were only altered for core production processes - not ancillary processes such as the production of inorganic chemicals using during manufacturing or the production of packaging materials.

Table A13: ReCiPe Life Cycle Impact Assessment Results

ReCiPe Midpoint and Endpoint Category [A]	*Unit*	*Functional Unit*	
		Handkerchief	*Facial Tissue*
Climate change Human Health	DALY	2.44E-05	4.08E-06
Ozone depletion	DALY	1.99E-09	5.89E-10
Human toxicity	DALY	2.20E-06	6.04E-07
Photochemical oxidant formation	DALY	2.16E-09	4.14E-10
Particulate matter formation	DALY	9.37E-06	1.07E-06
Ionising radiation	DALY	2.87E-08	1.41E-08
Human Health Total	**DALY**	**3.60E-05**	**5.76E-06**
Climate change Ecosystems	species.yr	1.38E-07	2.31E-08
Terrestrial acidification	species.yr	7.40E-10	5.97E-11
Freshwater eutrophication	species.yr	2.07E-10	4.01E-11
Terrestrial ecotoxicity	species.yr	5.14E-09	5.08E-11
Freshwater ecotoxicity	species.yr	3.55E-11	4.90E-12
Marine ecotoxicity	species.yr	5.67E-14	1.31E-14
Agricultural land occupation	species.yr	9.76E-08	1.13E-07
Urban land occupation	species.yr	2.34E-09	3.14E-09
Natural land transformation	species.yr	1.64E-07	2.37E-09
Ecosystems Total	**species.yr**	**4.08E-07**	**1.41E-07**
Metal depletion	$	9.51E-04	2.64E-04
Fossil depletion	$	71.6	12.1
Resources Total	**$**	**71.6**	**12.1**

[A] - ReCiPe midpoint and endpoint damage assessment values for the functional unit, using the Hierarchist version with the world normalization and average weighting set (ReCiPe H World ReCiPe H/A). Hierarchist represents the valuation of individuals who have a general faith in technology and government regulation of technology and is the midrange valuation method within ReCiPe. The model was also run using the Individualist (I) and Egalitarian (E) valuation methods and the overall data trends did not change.