Comparative Environmental Life Cycle Assessment of Hand Drying Systems:

The XLERATOR Hand Dryer, Conventional Hand Dryers and Paper Towel Systems

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About Quantis:

Quantis specializes in Life Cycle Assessment (LCA) and related applications. The company was founded in 2005 and has its global headquarters in Lausanne, Switzerland. It's US office is based in Boston, Massachusetts and has additional offices in Montreal, Canada and Paris, France. The company provides the highest level of expertise in delivering state-of-the-art analysis and solutions for leading companies, governments and non-profit clients.

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Executive Summary

Comparative Environmental Life Cycle Assessment of Hand Drying Systems:

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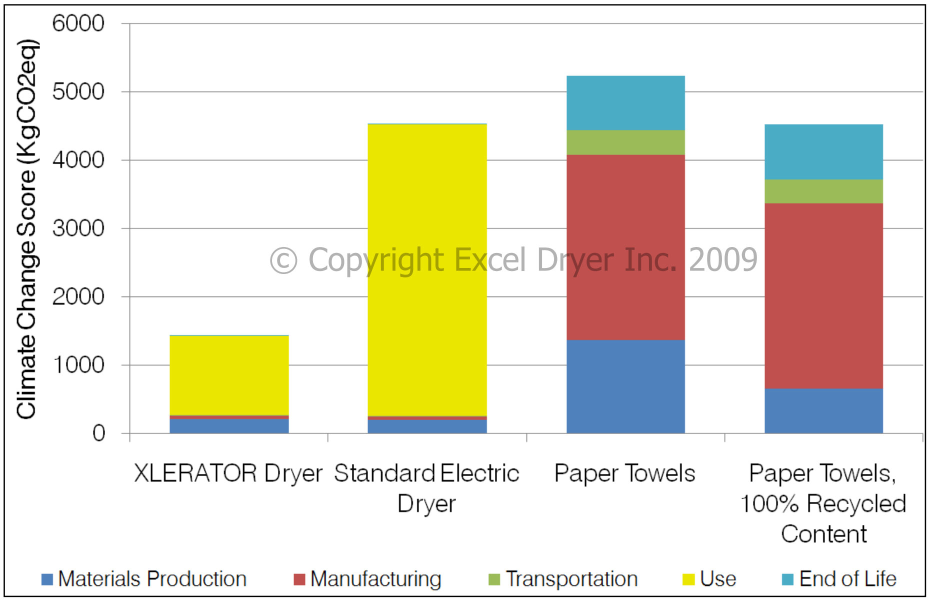
This report presents the results of an environmental life cycle assessment (LCA) comparing several systems for drying hands in public restrooms. The LCA method examines a broad range of environmental impacts at all stages of a product life cycle, from "cradle to grave" and including all material, energy, and pollutant inputs and outputs. The systems compared here include a conventional and high-efficiency electric hand dryer, and paper towels containing between 0% and 100% recycled content.

The results of the study indicate that the high-efficiency electric hand dryer, the XLERATOR, provides significant environmental benefits over the course of its life in comparison to the other options considered. The major cause of its advantage in comparison to conventional electric hand dryers is the reduction of the electricity consumption during the use of the dryer by nearly 4-fold. In comparison to paper towels, the combined environmental impact of producing the paper towels and associated materials far exceed the impact from the use of the XLERATOR. Although the use of recycled paper fibers in the towels *may* reduce the impacts of this system, even at 100% recycled content, the XLERATOR maintains a significant margin of benefit. A wide variety of sensitivity tests and scenario evaluations demonstrate that the margin of benefit for the XLERATOR is quite substantial and not dependent on the assumptions or methods. A test of uncertainty in the results shows that the confidence in the benefit of the XLERATOR in comparison to the other systems drier is quite high.



Under the baseline study assumptions, the paper towels show similar environmental performance to the conventional electric dryer: resulting in a slight increase or decrease, the direction of which will depend on variations in the product, its use and the assumptions of the study.

Among the sensitivity tests that have been conducted are variation in the amount of recycled content for the towels, the method for allocating impacts to this recycled content, the assumed source of electricity, and the behavior of the user. The scenarios concerning the amount of recycled content and the method for allocating the impacts of recycled paper content show that even the best-case method for the paper system and at 100% recycled content, the XLERATOR maintains a significant environmental advantage over the towels.

The scenarios regarding user behavior reveal the important role the user plays in determining the overall impacts of each system. "High intensity" users will cause a significantly larger impact and the increase is nearly in proportion to the amount of dry-time or length of towel used. Even "high intensity" users of the XLERATOR system remain at a lower level of impact than "low intensity" users of other systems.

A sensitivity test to examine the use of coal-based electricity versus the average US grid suggests that the choice to use the US average has not significantly influenced the outcome of the study. A scenario using wind power for production and use of the systems suggests that use of the electric hand dryers with renewable energy is the most environmentally friendly option. While paper towel systems may see improvements through energy savings or use of renewable energy in manufacture, the potential for increase is unlikely to be sufficient to allow them to surpass high-efficiency electric hand dryers.

1 Introduction

1.1 Overview and Context

Excel Dryer, Inc. (Excel) has developed and is marketing a hot air hand dryer (the XLERATOR) that is an industry leader in per-use energy efficiency. While a comparison to other hot air hand dryers in use-phase energy efficiency is straight-forward, it is not clear how this product compares with conventional hand dryers in other stages of the life cycle and for a complete set of environmental performance metrics. In addition, there is a need to understand the relative environmental impacts of these electric hand dryer systems with other alternatives in fulfilling the same function, most notably paper towels.

The proper framework for considering such issues is environmental life cycle assessment (LCA), which is an internationally recognized basis for identifying and comparing the total impacts of producing and consuming a product or service. Quantis has performed a comparative LCA of the XLERATOR hand dryer, a conventional hot air hand dryer, and paper towels of varying recycled content. The study has been performed in accordance with international standards in the field of LCA and has been reviewed by an external panel of LCA experts and practitioners. The findings show a substantial environmental advantage for the XLERATOR hand dryer system.

1.2 Life Cycle Assessment Methodology

LCA methodology has been developed to better understand and address the potential impact associated with products and services throughout their life cycle. LCA addresses the environmental aspects and potential environmental impact (*e.g.*, use of resources and the release of pollutants) throughout a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal. LCA bases all results in relation to a well-defined functional unit, allowing for direct comparisons among competing products or systems, as well as alternate forms of the same product or system. Among other uses, LCA can: identify opportunities to improve the environmental performance of products at various points in their life cycle; inform decisions (*e.g.*, strategic planning, priority setting, product or process design); inform the selection of environmental performance indicators and measurement methods; support marketing efforts (*e.g.*, producing an environmental product declaration); and more.

An LCA is comprised of four phases:

a) **Goal and scope definition:** defining the purposes of the study, determining the boundaries of the system life cycle in question and identifying important assumptions that will be made;

b) **Inventory analysis:** compiling a complete record of the important material and energy flows throughout the life-cycle, in additional to releases of pollutants and other environmental aspects being studied;

c) **Impact assessment:** using the inventory compiled in the prior stage to create a clear and concise picture of environmental impacts among a limited set of understandable impact categories; and

d) **Interpretation:** identifying the meaning of the results of the inventory and impact assessment relative to the goals of the study.

LCA is best practiced as an iterative process, where the findings at each stage influence changes and improvements in the others to arrive at a study design that is of adequate quality to meet the defined goals. The principles, framework, requirements and guidelines to perform an LCA are described by the international standards ISO 14040 series.(ISO 2006)

2 Goal and Scope

2.1 Objective of the Study

Objectives

The objectives of the present study are:

I. To comprehensively **define the environmental impacts** over the whole life cycle of the product systems studied;
II. To provide an accurate **comparison of impacts** among the systems studied, including a wide range of environmental impact metrics; and
III. To provide an assessment of the **influence of several key variables** or characteristics, such as the intensity of use (duration per dry for electric hand dryers, towels per dry for paper towels), recycled content, alternate electricity sources, and/or other aspects.

The intended audiences and uses for the study include manufacturers of products for purposes of product improvement, purchasers of hand-drying systems to assist in their purchasing decisions, and other interested parties, including the public. It is intended to provide these audiences with information needed to make a valid comparison of the life cycle environmental impacts of the systems in question. It is important to note that the impacts described here are *estimates* of *potential* impacts, rather than direct *measurements* of *real* impacts.

The work presented here has been compiled in a combination of Microsoft Excel and SimaPro software.

2.2 Function and Functional Unit

The purpose of the products in question is to dry hands after washing in a public restroom. The functional unit for this study is ***to dry 260,000 pairs of hands.***

It is believed that this functional unit represents a typical service rate for a single installation of any of the systems over a 10-year lifetime (500 uses per week). This 10-year lifetime was suggested by Excel Dryer, Inc. as a lower range of the likely lifetime of such systems. No measurements are known for the actual average service life of such systems. Neither is there any basis to assume one system would have a greater service life than another.

The functional unit provides a basis for comparing all life cycle components on a common basis: namely, the amount of that component required to fulfill the described function. It also allows direct comparisons among the product systems in question.

While it is possible that the systems may have secondary functions, such as regarding hygiene, for purposes of the present study it is assumed that any other functions are equivalent among the systems and that they can be evenly compared on the basis of the hand-drying function alone. To help ensure equivalent function, units that do not require the user to touch them (i.e., with optical controls) have been chosen for all hand drying systems.

2.3 System Description

The three products under study are options for providing hand-drying services in public restrooms. One product, the XLERATOR hand dryer is an energy efficient and high-speed hot air hand dryer. A second product is a conventional air hand dryer, typical of the leading options in this market over the past several decades. The third system is paper towels, including several scenarios regarding the percent of recycled content. Important aspects of these systems are show in Table 1. Additional information regarding each system is provided in the appendices.

Table 1: Key Characteristics of the Products Studied (baseline scenarios)

	 **XLERATOR Hand Dryer**	 Conventional Hand Dryer	 Paper Towels
Functional Unit	Drying 260,000 Pairs of hands		
Product needed for Functional Unit	One dryer and 1381 kWh electricity	One dryer and 5108 kWh electricity	One dispenser plus 37,960 m^2 of paper towel
Housing Components	Zinc, stainless steel or reinforced resin (even combination of 3 optional covers)	Zinc and aluminum	Polypropylene
Internal components	Motor, fan, optical sensor, wiring	Motor, fan, optical sensor, wiring	Motor, optical sensor, batteries
Manufacturing Location	East Longmeadow, Massachusetts, USA	USA	USA
Distribution	Shipped as single units or on pallets to distributor	Shipped as single units or on pallets to distributor	Shipped as single units or on pallets to distributor.
Supply Chain Distances	750 km by truck and 750 km by ship for all components	750 km by truck and 750 km by ship for all components	750 km by truck and 750 km by ship for all components
Packaging Material	Plastic liner bag within corrugated cardboard box, with molded pulp end caps	Plastic liner bag within corrugated cardboard box, with molded pulp end caps	Dispenser in plastic liner bag within corrugated cardboard box, with molded pulp end caps; towels in corrugated cardboard box.
Recycling Rate	Packaging recycled at national material averages (U.S. EPA 2007); dryer components not recycled	Packaging recycled at national material averages (U.S. EPA 2007); dryer components not recycled	Packaging recycled at national material averages (U.S. EPA 2007); dispensor components not recycled; towels not recycled
Use Phase Assumptions	12 second run time with 1500 watts of electricity draw (plus 1.5 second shutdown at half power)	30 second run time with 2300 watts of electricity draw (plus 1.5 second shutdown at half power)	2 towels used, with 0.073 m^2 area per towel.

2.4 System Boundaries and Characteristics

The life cycles of the electric and paper towel hand drying systems were divided into five principal life cycle stages: (1) **Material Production**; (2) **Transportation** (including to the production site, to the point of use and to the end-of-life location; (3) **Manufacturing**; (4) **Use**; and (5) **End of Life** (landfilling, recycling or incineration). Within each of these stages, the LCA considers all identifiable "upstream" inputs to provide as comprehensive a view as is practical of the total influence of the product system. For example, when considering energy used for transportation, not only are the emissions and fuel used by the truck moving the products considered, but also the additional processes and inputs needed to produce that fuel. In this way, the production chains of all inputs are traced back to the original extraction of raw materials.

The study has been conducted with an intention of being applicable to the US market for the products in question and to represent conditions at the current time (2009). All components have been included in cases where the necessary information is readily available or a reasonable estimate can be made. In cases where information is not available, components may have been omitted only if their impacts are anticipated to fall well below 1% of the total system impacts. Examples include small components of the dryer and dispenser assemblies, such as labels and screws. The weight criterion was the only one used for exclusion. The following figures show the stages of the life cycle for the three systems and provide information on the amount of materials, energy or other processes involved for key portions of the lifecycle. For simplicity, numerous minor materials and processes have not been shown individually. The appendix contains a full listing of the reference flows for each system.

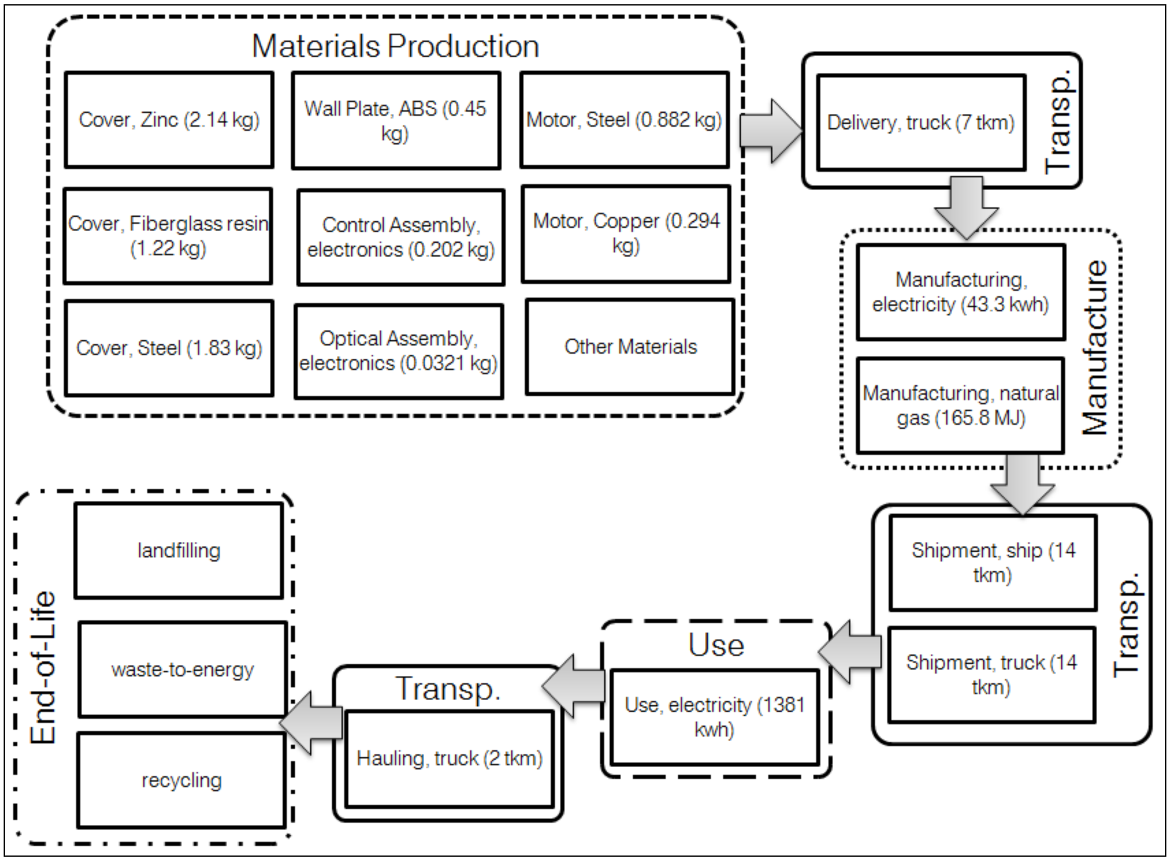


Figure 1: Diagram of life cycle system boundary and key reference flows for the XLERATOR system

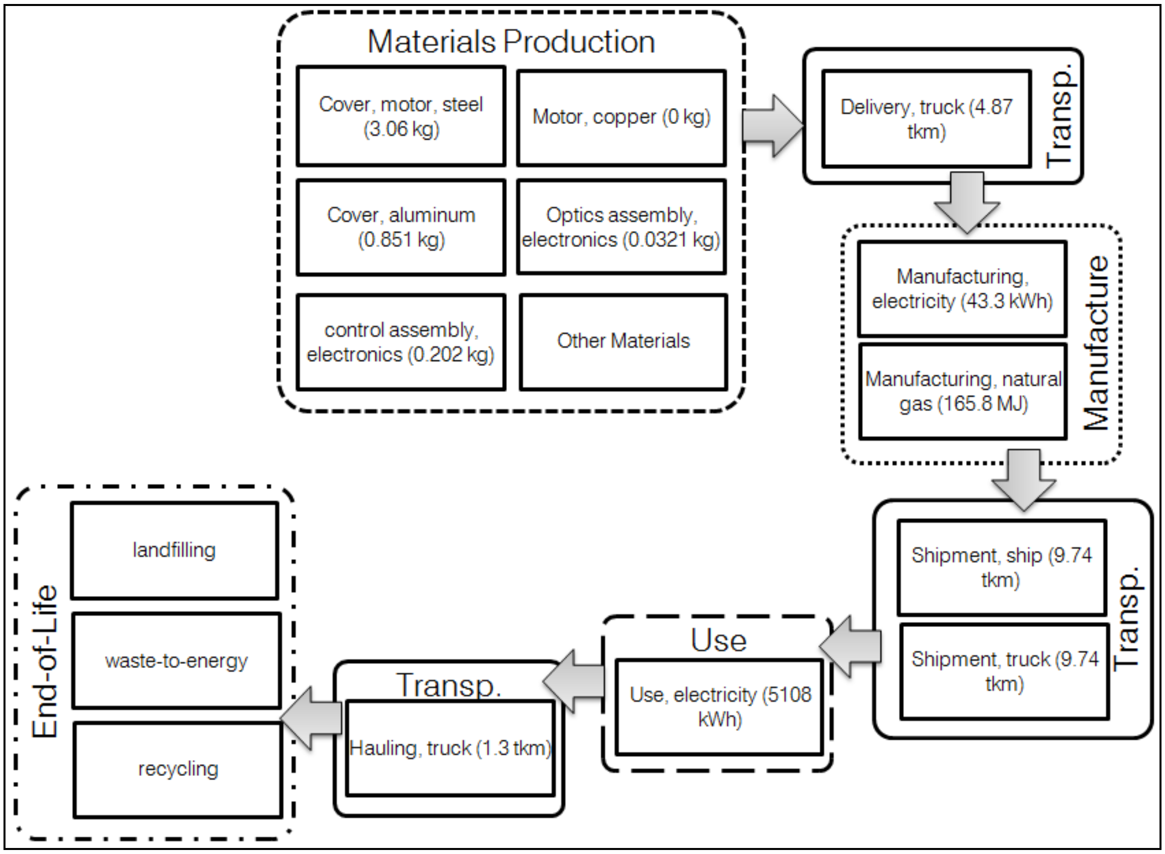


Figure 2: Diagram of life cycle system boundary and key reference flows for the conventional hand dryer system

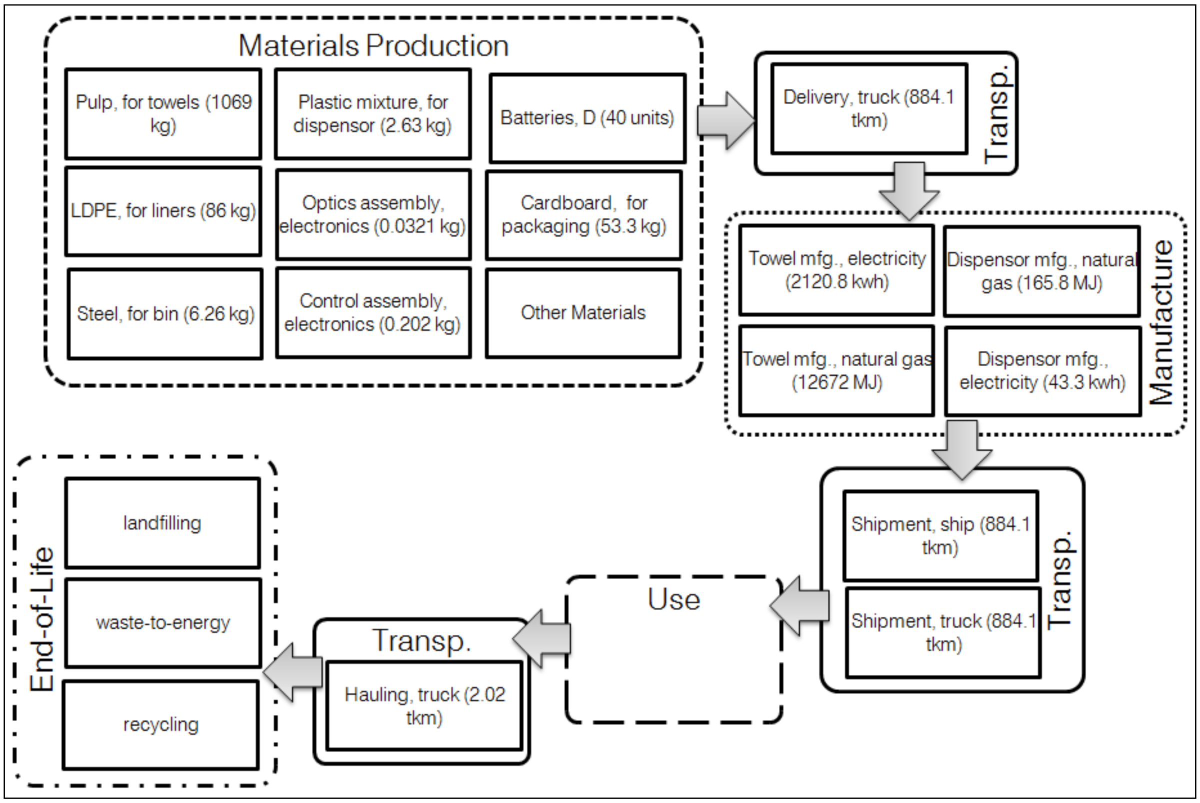


Figure 3: Diagram of life cycle system boundary and key reference flows for the paper towels system

For the hot-air electric hand dryers, it might be assumed that an indirect effect on heating/cooling energy could be caused by the heat produced by these units. For example, during heating season (the portion of the year when buildings are heated), the heat produced by the hand dryers would cause less energy to be consumed by a building's heating system and in cooling season more energy would be consumed. Accounting for this requires a variety of assumptions about geographic location and the efficiency of buildings and their heating/cooling efficiencies that are beyond the scope of the present study. However, this consideration should be noted and it can be said that the present results are therefore likely to overstate the environmental impact of electric hand dryers in climates where the heating season is dominant and to understate them where the cooling season dominates.

2.5 Inventory Data and Information Collection

In obtaining and selecting among available data, considerations of representativeness, consistency, accuracy and geographic and temporal relevance have been considered. The data has been selected that best meets this combination of criteria. With the exception of information on the impacts of disposing of batteries in municipal landfills and the impacts of producing recycled paper pulp, there were no data points that were felt to be poor in their combination of the criteria listed above.

For the conventional electric hand dryer and paper towel systems, data has been sought that falls within the range of common properties of those systems on the market and, where adequate data is available, to be close to the average of that range. For the XLERATOR system, higher quality information has been collected to represent this specific system. In a few cases, such as in transportation logistics, the more generic information used for the other systems have been used in place of better quality data for the XLERATOR system to ensure that the more accurate data available for the XLERATOR system did not result in a bias toward that system. For example, although Excel Dryer, Inc. was able to provide information showing that their suppliers' delivery distances are less than those assumed for the other systems, we have used the same assumption for all systems.

For the XLERATOR hand dryer, most data were obtained directly from the manufacturer (Gagnon and Panaretos 2009). Information regarding production, distribution and use of the XLERATOR hand dryer, including manufacturing inputs, manufacturing processes, distances of immediate suppliers, distribution distances, transportation modes and use information was collected directly from Excel's staff via email, phone calls and in-person discussions and observation during a site visit. In a few cases, approximations have been made based on the best judgment of the appropriate staff members. For example, that electric hand dryers would require about 1.5 seconds at a declining power to shut off once the user completed their use of it. Table 6.3 lists the major characteristics of each system and from where the information has been obtained.

For the conventional hand dryer, data were obtained from Excel Dryer, Inc. (Gagnon and Panaretos 2009), which manufactures such units and from a prior screening-level LCA report on such systems (Environmental Resources Management 2001). For paper towels, much information was drawn from a recent carbon foot-printing publication supported by a major manufacturer of such towels (Madsen 2007). The information taken from these sources is reflected in the tables of reference flows and study assumptions in the appendix.

For background life cycle inventory data, the European ecoinvent inventory database (v 2.01) was used for this study as it is a very comprehensive database, both in terms of technological and environmental coverage (Althaus, Doka, and Dones 2007; The Ecoinvent Center 2007; Frischknecht, Jungbluth, and Althaus 2005). It should be noted that using European data to represent North American processes can introduce some bias in certain areas. However, it is believed that the consistency and accuracy of this database make it a preferable option for representing North American conditions compared to other available data for most processes. In addition to the consideration of geographic relevance, one must also consider temporal relevance, consistency, completeness and other quality criteria. The opinion of the authors is that ecoinvent is superior to other available data sources on these other criteria by a considerable enough margin to overshadow any concern over geographic relevance. In addition, although ecoinvent is of European provenance, it contains information representing many regions of the world. For example, the data we have used to represent electricity use is data created to represent the US electricity grid, even though it is a part of the ecoinvent database.

One of the key references for characterizing the systems (Environmental Resources Management 2001) is based on European (UK) conditions. The major hand-drying systems in that marketplace do not differ significantly from those in North America.

The US electricity grid mix has been used for all foreground processes, meaning those that have been directly modeled as reference flows for one of the systems and listed as being represented by electricity in Table 4. A substitution of the US grid mix into the background of all processes has not been done. Because the supply chains of each system are not known, it is unclear that this would result in greater representativeness of the true source of electricity used within the supply chains. In the scenarios using coal or wind electricity, only the foreground processes have been substituted.

In three cases, sufficiently representative data was not available in ecoinvent. In two of these cases, batteries and chrome electroplating, data was taken from the IDEMAT database (Delft University of Technology 2001). Although the quality of data in the IDEMAT database can be regarded as reasonably accurate, there are also comparability concerns regarding the use of this data in a study otherwise composed entirely of data from a single source. In the third case, the production of recycled pulp, an acceptable source of data was not able to be found. The data for production of recycled paper products in ecoinvent does not differentiate between the production of pulp and the production of the products (see, e.g., table 8.88 in Hischier 2007). A value for electricity use is available in Madsen 2007 (174 MJ electricity to produce 60.1 kg of pulp, from figure 3.9 of that reference), but the documentation is not complete enough to assess what processes other than electricity use should be accounted for. This electricity value has been applied as a scenario to examine the potential importance of the lacking data on recycled pulp production, however it is not included in the baseline scenario due to concerns over its quality.

2.6 Life Cycle Impact Assessment Method

For the present study, *Climate Change Score*, *Water Use, Human Health, Ecosystem Quality, and Resource Depletion* have been selected as the primary impact categories. In the impact assessment, the flows of materials, energy and emissions into and out of each product system are classified and combined based on the type of impact their use or release has on the environment. Described below are the methods used here for estimating environmental impacts.

The IMPACT 2002+ impact assessment methodology (Jolliet et al. 2003) has been chosen because it is felt that it represents the best available science in life cycle impact assessment at the time of initiation of this study. In comparison to other methods that might be considered equally robust, it has been selected due to the existence of a method based on scientific principles for combing “midpoint” indicators that affect a similar endpoint into a single “endpoint” indicator, allowing for a clearer and comprehensive communication of outcomes. In the case of climate change, a modification has been made to the IMPACT 2002+ methodology through substitution of a more current climate change impact assessment method, as described below.

IMPACT 2002+ makes assessment of environmental damages at what are known as “midpoint” and “endpoint” (also called “damage”) environmental indicators. Endpoint indicators are those that attempt to quantify most directly the subject of concern in terms of damages to health or the environment. For example, the Human Health endpoint indicator in IMPACT 2002+ attempts to estimate us the years of useful life lost (DALYs, disability adjusted life years) due to all the human health impairments that can be quantified with the methodology. Similarly, the Ecosystem Quality indicator reports on the amount of species loss that might occur.

Midpoint indicators, in contrast, are steps along the way to calculating the endpoint indicators. For example, the total amount of photochemical oxidation that is caused by all pollutant releases is one midpoint indicator in the IMPACT 2002+ system, and can be combined with many other midpoint indicators to determine the total Human Health endpoint indicator. A schematic of the IMPACT 2002+ system, as implemented here, is show in Figure 4.

The midpoint indicators for the IMPACT 2002+ system have also been evaluated to provide additional detail on specific areas of environmental impact and to ensure that the method used to combine these into an endpoint indicator has not resulted in the masking of some categories for which opposite directional results are obtained. In addition, midpoint indicators from a second system, the Tool for the Reduction and Assessment of Chemical Impacts (TRACI, Bare *et al.*, 2003), have been evaluated to ensure that the results are consistent when assessed with a second methodology. While IMPACT 2002+ is calibrated to European conditions, TRACI is calibrated to North America and it therefore also serves as an assurance that geographic differences have not significantly biased the results.

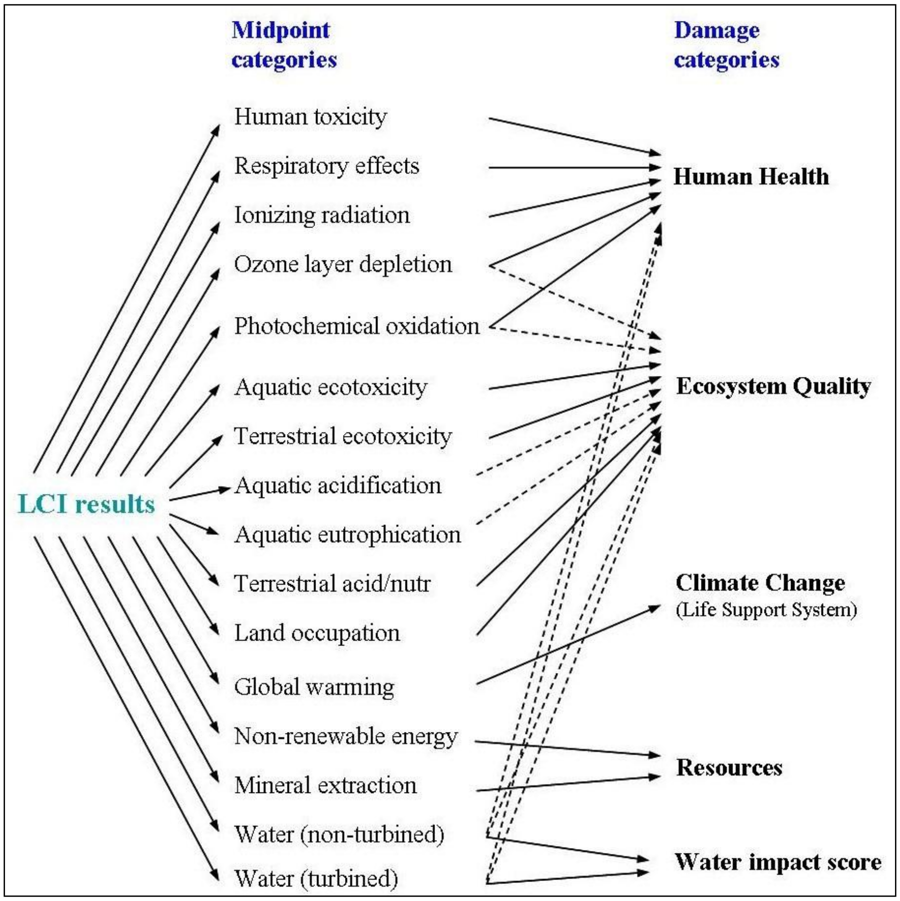


Figure 4: IMPACT 2002+ impact assessment system, updated to include water use (adapted from Jolliet *et al*. 2003)

In moving from inventory level information (e.g., kilograms of acetone emissions) to midpoint level indicators (e.g., photochemical oxidation) to endpoint indicators (e.g., human health), there is a trade-off in types of uncertainty (Weidema, 2009). There is uncertainty included in modeling necessary to produce midpoint and endpoint indicators. This implies that we know the value of these indicators with less certainty than we do for the flows of individual materials in the life cycle inventory. However, in moving to midpoint and then endpoint indicators, there is a reduction in uncertainty related to interpretation; that is, the information is presented in a way that is more immediately relevant and able to be interpreted. With the exception of climate change and water use, the information presented here is at the endpoint level. For climate change and water use, it is felt that the uncertainty in converting these impacts to endpoint indicators is too great to justify and there is significant interest by likely audience members to see this information separately. Each of the impacts reported on here is described briefly below.

Climate Change is represented based on the International Panel on Climate Change's 100-year ratings of the Global Warming Potential of various substances (IPCC 2007). Substances known to contribute to global warming are adjusted based on an identified Global Warming Potential, expressed in kilograms of CO_2 equivalents. Because the uptake and emission of CO_2 from biological sources can often lead to misinterpretations of results, it is not unusual to omit this biogenic CO_2 from consideration when evaluating Global Warming Potentials. Here, we have followed the recommendation of the Publicly Available Standard (PAS) 2050 product carbon footprinting guidance in not considering either the uptake or emission of CO_2 from biological systems and correcting biogenic emissions of other gasses accordingly by subtracting the equivalent value for CO_2 based on the carbon content of the gas (BSI 2008).

Freshwater Use is a challenging category of impacts to represent in LCA due to the variations in impact among locations and the difficulty of linking withdrawals to environmental or health issues. Because many inventories of freshwater use are dominated by turbined water (for electricity generation), which is not generally removed from the watercourse but rather used and then returned, accounts of total freshwater use can be misleading and poorly reflective of water scarcity concerns. In the present study, we have divided freshwater uses among the non-consumptive uses (i.e., turbined water) and consumptive uses. Water designated as being for cooling and water of unspecified origin have both been included in the non-turbined (consumptive) category. Both turbined and non-turbined water use has been divided by the total per-capita annual usage of each type within the US (Hutson et al. 2004) (USGS 2009). The results are then reported as person-years of water use, corresponding to the average per-capita usage within the United States. This is referred to throughout this report as "water use" and includes only freshwater, not oceanic water.

Human Health impact can be caused by the release of substances that effect humans through acute toxicity, cancer-based toxicity, respiratory effects, increases in UV radiation and other causes. An evaluation of the overall impact of a system on human health has been made following the Human Health end-point in the IMPACT 2002+ methodology (Jolliet et al. 2003), in which substances are evaluated based on their ability to cause each of a variety of damages to human health.

Ecosystem Quality can be impaired by the release of substances that cause acidification, eutrophication, toxicity to wildlife, land occupation, and a variety of other types of impact. An evaluation of the overall impact of a system on ecosystem quality has been made following the Ecosystem Quality end-point IMPACT 2002+ methodology (Jolliet et al. 2003), in which substances are evaluated based on their ability to cause each of a variety of damages to wildlife species.

Resource Depletion is caused when non-renewable resources are used or when renewable resources are used at a rate greater than they can be renewed. Various materials can be given greater importance based on their abundance and difficulty to obtain. An evaluation of the overall impact of a system on resource depletion has been made following the Resources end-point in the IMPACT 2002+ methodology (Jolliet et al. 2003), which combines non-renewable energy use with an estimate of the increased amount of energy that will be required to obtain additional incremental amounts of substances from the earth due to removal of resources inventoried for each system (based on the Ecoindicator 99 method). Non-renewable primary energy use accounts for the consumption of fossil and nuclear resources but excludes sources of renewable energy at all stages of the life cycle and in all upstream processes. This metric is expressed here in megajoules.

2.7 Scenarios and Sensitivity Tests

In addition to the baseline scenario for each system, the following scenarios were modeled for purposes of comparison:

- Recycled content of paper towels: A series of scenarios were run to consider paper towels with differing recycled fiber content. These scenarios include 0% (the baseline scenario), 20%, 40%, 60%, 80% and 100% recycled content. These scenarios have been created to coincide with the scenarios on allocation methods described below.

- Recycled content allocation method: When recycled content is used in a system, there is a methodological choice that must be made regarding how to apportion the impact or benefit from the production and/or disposal of that material among the several systems it may be a part of. While there is no clear scientific consensus regarding an optimal method for handling_this in all cases (Reap et al., 2008), many possible approaches have been developed and each may have a greater level of appropriateness in certain circumstances. Although the case of paper towels is simpler than some due to the lack of recycling at end-of-life, the allocation remains a crucial methodological choice for this system. To test the importance of this methodological choice, several allocation approaches have been applied as scenarios. The baseline scenario throughout this report allocates to the paper towels no impacts from the original production of recycled paper pulp, but 100% of impacts of producing recycled pulp from prior use and allocating 100% of impacts of disposal of the amount of product which is not further recycled (in this case, 100%). This is the “cut-off” method suggested by Ekvall and Tillman (1997). In addition, scenarios are conducted that include allocating 50% of the impacts from original pulp production, recycling from prior use and from disposal; and allocating 0% for the original production and final disposal stages to the paper towels (a “best case scenario” for the towels). The appendix contains a lengthier discussion on allocation.

- Source of electricity (grid mix): Because both of the electric hand dryer systems are highly driven by electricity use during their use phase, it is advisable to consider several scenarios of the assumed origin for this electricity. Similarly, there is a significant contribution of electricity to the production impacts of the paper towel. The baseline assumption is that electricity is derived from the mix of the technologies supplying electricity to the U.S. electricity grid based on their annual rates of production. While this is a common assumption to make within LCA, some would argue that it may be more appropriate to consider the marginal electricity production technology (that which is most likely to be increased or decreased in response to changing demand, called the “consequential” approach in LCA). In the U.S., this marginal technology is primarily coal-burning electricity plants. A scenario is therefore run where all electricity in the use phase and manufacturing is from coal burning. In addition, a scenario is run where all electricity during the use phase and in manufacturing is from wind power. This shows a “best case” for the electric hand dryer systems and shows the potential improvement if the user were to obtain their energy from a source that can credibly claim to be renewable. It should be pointed out that results might vary slightly for other renewable energy technologies. Wind has been chosen as an example because it is a common source of electricity marketed in the US as berg from a certified venerable source.

- Intensity of use: It is anticipated that the behavior of the user of each system will have a substantial influence on the impact of the system. The user can control the length of time that the electric hand dryer is run and can control the amount of towel that is used. A set of three scenarios have been run to show the variation in impacts from a “low intensity,” “moderate intensity,” and “high intensity user.” For the XLERATOR, these users are assumed to use 8 seconds, 12 seconds and 16 seconds of drying time, respectively. The times are 20 seconds, 30 seconds and 40 seconds for the conventional electric hand dryer . For the paper towel systems, the usage rates are 1 towel, 2 towels, and 3 towels.

3 Results

Complete results for each of the chosen indicators for each life cycle stage are provided in the appendices. In the sections below, the discussion will prominently feature the Climate Change impact category, with some mention of other indicators in situations where the findings are particularly noteworthy.

3.1 Overview

The total climate change score for the baseline scenario for each system is shown in Figure 5.

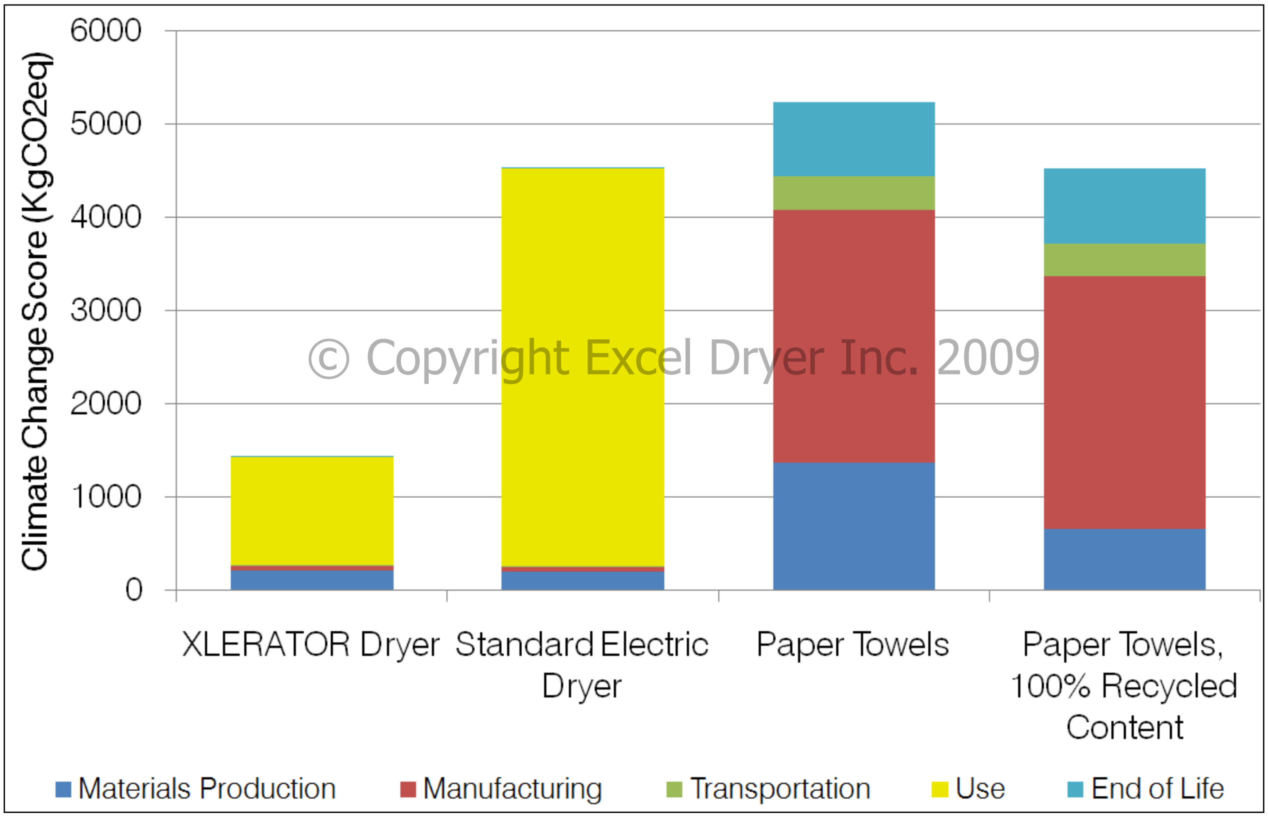


Figure 5: Total life cycle climate change score for each of the systems

In total, the climate change score for the conventional electric hand dryer s are shown to be 220% higher than the climate change score for XLERATOR, the standard paper towels are 270% higher and the 100% recycled content towels are 220% higher.

Figure 6 shows the results for each of the five impact indicators studied. They are shown as a percentage of the total for the XLERATOR system.

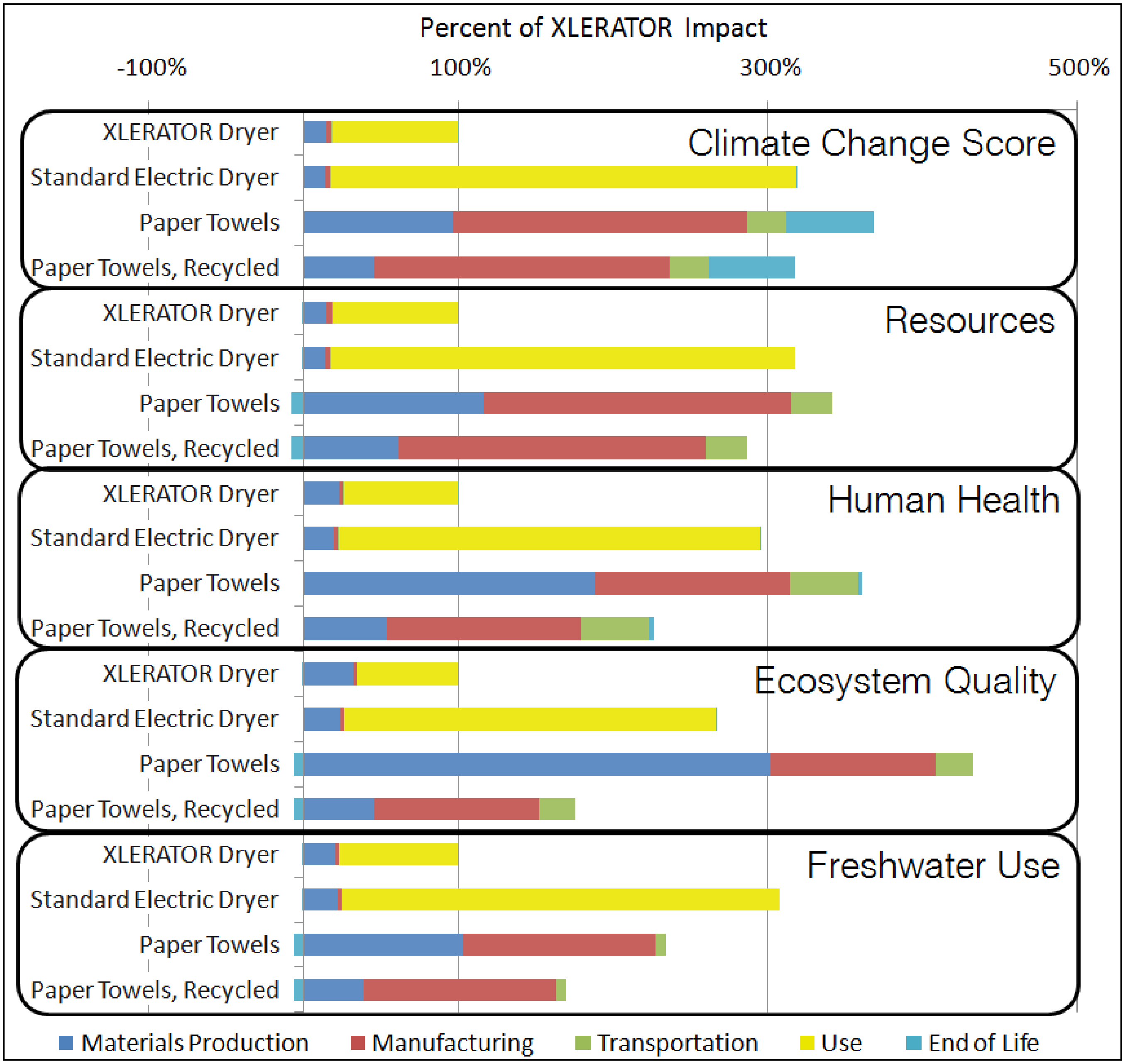


Figure 6: Total life cycle impacts of each system as a percentage of the impacts of the XLERATOR system for each of the five indicators studied. *Note that some systems show a small benefit (negative impact value) at end of life which should be factored in when judging the total. These are shown as values to the left of the axis.*

The XLERATOR is the best performing system for all indicators examined. Numerical results by life cycle stage for each indicator measured are shown in section 6.1. Greater detail is provided in section 6.2, which shows the impact assessment results for each reference flow used to characterize the systems.

3.2 Contributors by Life Cycle Stage

As seen in Figures 5 and 6, the materials production and use phase are dominant for the electric hand dryers (with the use phase being much more dominant for the conventional hand dryer) and the materials production, manufacturing and transportation stages are dominant for the towel systems. For the towel systems, the end-of-life stage is moderately important for the climate change score, but of minor importance for the other indicators. Among the various components of the towel system (including the towels, dispenser, batteries, waste bin and liners), the towels contribute between 89 and 94% of the total impacts across all life cycle stages, depending on which impact category is considered.

The following sections present the results for each system by the stages of the life cycle. It should be emphasized that comparisons among systems for individual stages of the lifecycle are not meaningful and this information is presented only to further explain the trends seen for the whole life cycle.

Materials production

Figure 7 and Figure 8 shows the contributors to the Materials Production stage for each of the systems. 100% recycled towels are not shown.

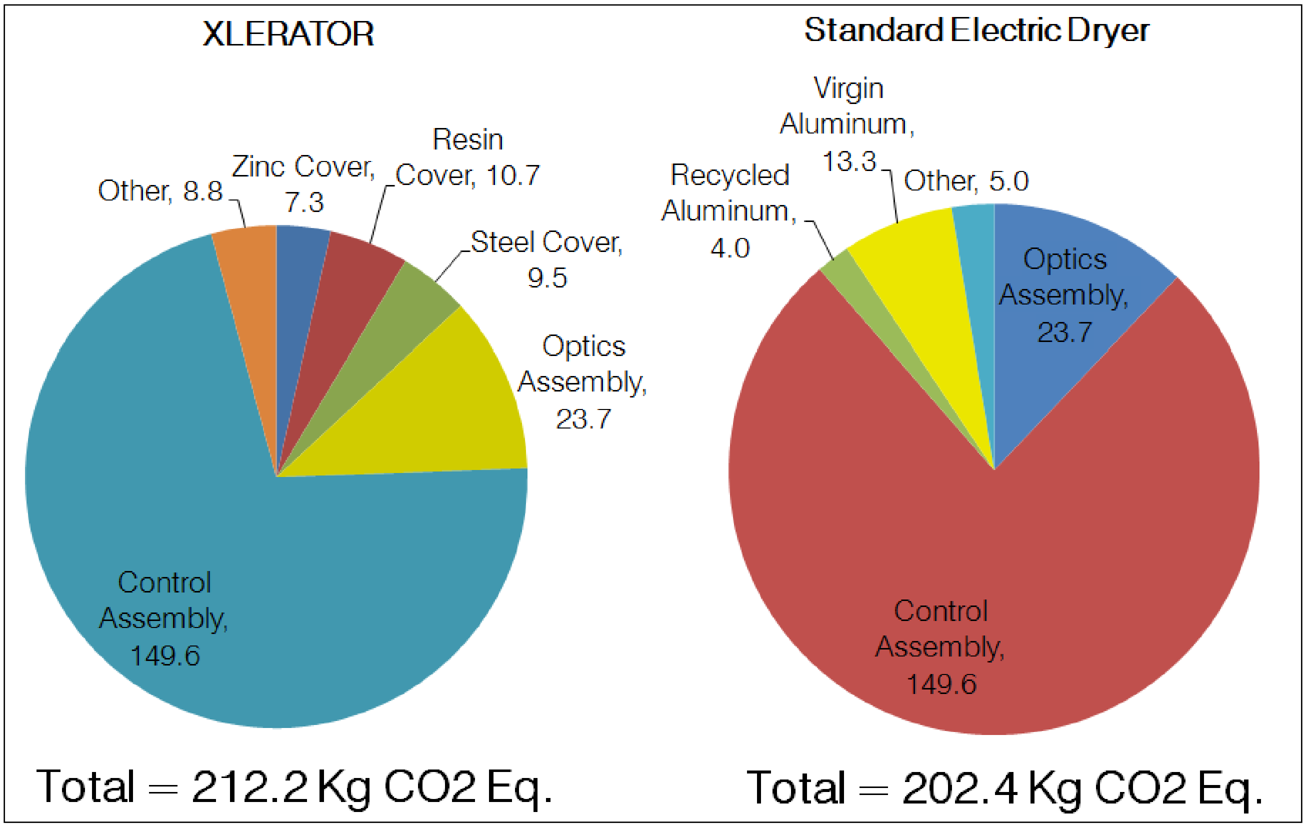


Figure 7: Climate Change Score for Materials Production of the Electric Hand Dryer Systems

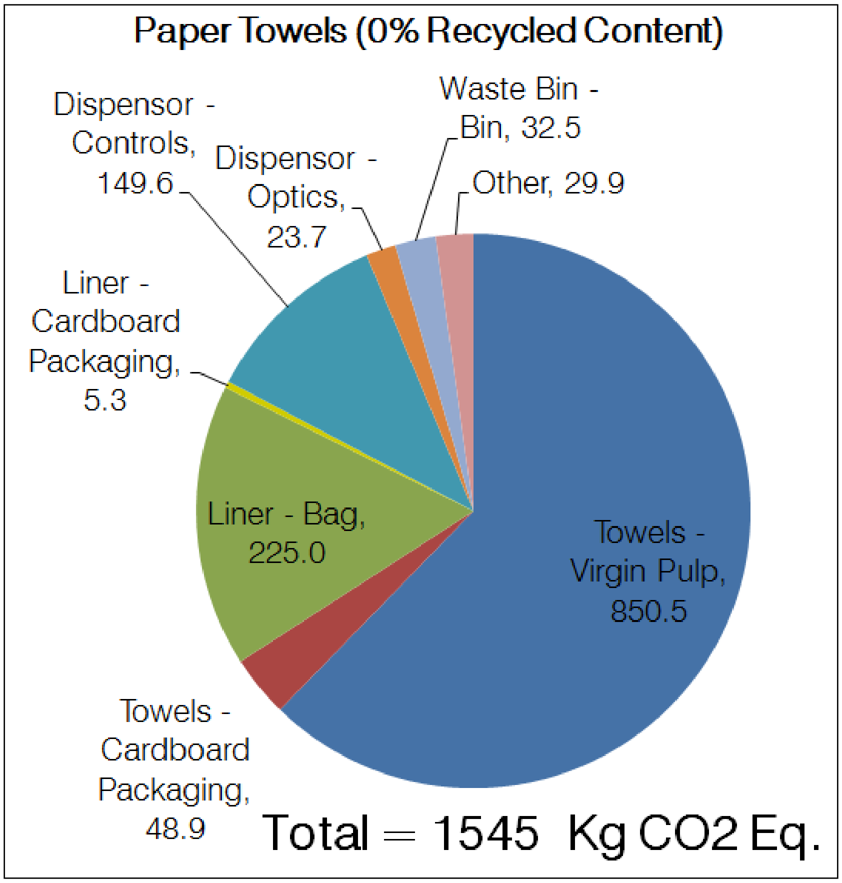


Figure 8: Climate Change Score for Materials Production of the Paper Towels System

Within the electric hand dryer systems, it is the electronic components that represent the greatest climate change impacts within the Material Production stage. The cover and frame materials provide the majority of the remainder. As noted in
Table 1, the XLERATOR is represented as an equal mixture of the three housing options. The results show that the various options will modify the total life cycle impacts by approximately 10 kg CO_2 Eq. For the zinc and resin covers, there are plating and paint impacts that are included in the *other* category in Figure 7.

For the paper towels, it is the virgin pulp production that contributes most to the Material Production stage climate change score. The trash liner bags, packaging and electronic dispenser controls are also significant contributors. For recycled paper towels, the impacts at this stage would vary between 3 and 6-times the impacts of the electric hand dryers depending on the percent of recycled content and the allocation factor that is applied to this content.

Manufacturing

Within the manufacturing stage, the impacts for the electric dyer systems are those of manufacturing the hand dryer and are approximately 48 kg CO2 Eq. per dryer (and per functional unit). For the paper towel system, a similar magnitude of impact is incurred in the manufacturing stage of the dispenser. In addition, approximately 2660 kg CO2 Eq. of climate change impacts are incurred in the manufacturing stage of the paper towels. These impacts are assumed to be the same for towels containing both virgin and recycled content. Manufacturing impacts for waste bags, bins and packaging are roughly approximated within the Materials Production stage by using standard materials formation LCI processes (such as film extrusion for liner bags) and are not included in the Manufacturing stage.

Transportation

Transportation is of moderate importance for the towel systems (between 3 and 20%, depending on impact category), while of very little importance for the electric hand dryers (less than 1%). This is due to the much higher weight of material that must be transported in the paper towel system (more than 1000 kg, nearly 90% of which is paper towels, verses less than 10 kg of total weight for the hand dryer systems).

Use

Within the use phase, the impacts for the electric hand dryers are entirely attributed to the use of electricity. No impacts are identified for the paper towels, the impacts of all materials, including towels, dispensers, trash bins, liners, packaging and batteries are accounted for in the materials production and manufacturing stages. The conventional hand dryer uses 3.7-times more electricity during its lifetime than the XLERATOR and so all use-phase impact categories are 3.7-fold higher for this system.

End-of-Life

End-of-life is important for the climate change score of towels due to emissions of greenhouse gasses from landfills due to the degradation of the paper towels. It should be noted again that emissions of CO_2 from products of biological origin (e.g., paper) are not considered in this study and it is therefore primarily methane[1] that causes these end-of-life emissions from landfills to contribute as much as 20% of the total. End-of-life is of much lesser importance for the other impact categories and for the electric hand dryer systems. Within the towel system, it is the towels themselves, rather than the dispenser, waste bin, batteries or bin liners that are responsible for the majority of end-of-life climate change impact (>90%).

3.3 Scenarios, Sensitivity Tests and Uncertainty Assessment

As described above in section 2.7, numerous sensitivity tests and scenarios have been examined to examine the responsiveness of the results to varying conditions and to explore the strength of the findings to alternate assumptions. An uncertainty assessment has been conducted on the results for the climate change impacts and is presented in the appendix. The uncertainty assessment considers the range of measurement uncertainty in estimating the flows of material and energy in the systems and the uncertainty in the emissions of pollutants or other impacts associated with each of these. The results indicate that the differences among the XLERATOR and the other systems are quite significant, with the probability of the opposite conclusion being less than one in one million for the climate change score.

Recycled Content

To examine the variation in results depending on alternate recycled content of paper towels, scenarios have been conducted in which this percentage was varied between 0% and 100%. Figure 9 shows the results of these scenarios for the climate change score. A table in the appendix shows the results for other impact categories. All other conditions are the same as in the basic scenario.

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[1] As described in section 0, biogenic methane is assigned a Global Warming Potential of 22.25 (rather than the 25 for fossil methane) in the method used here to account for the 2.75 kg of CO2 taken up by biota in producing one kg of methane.

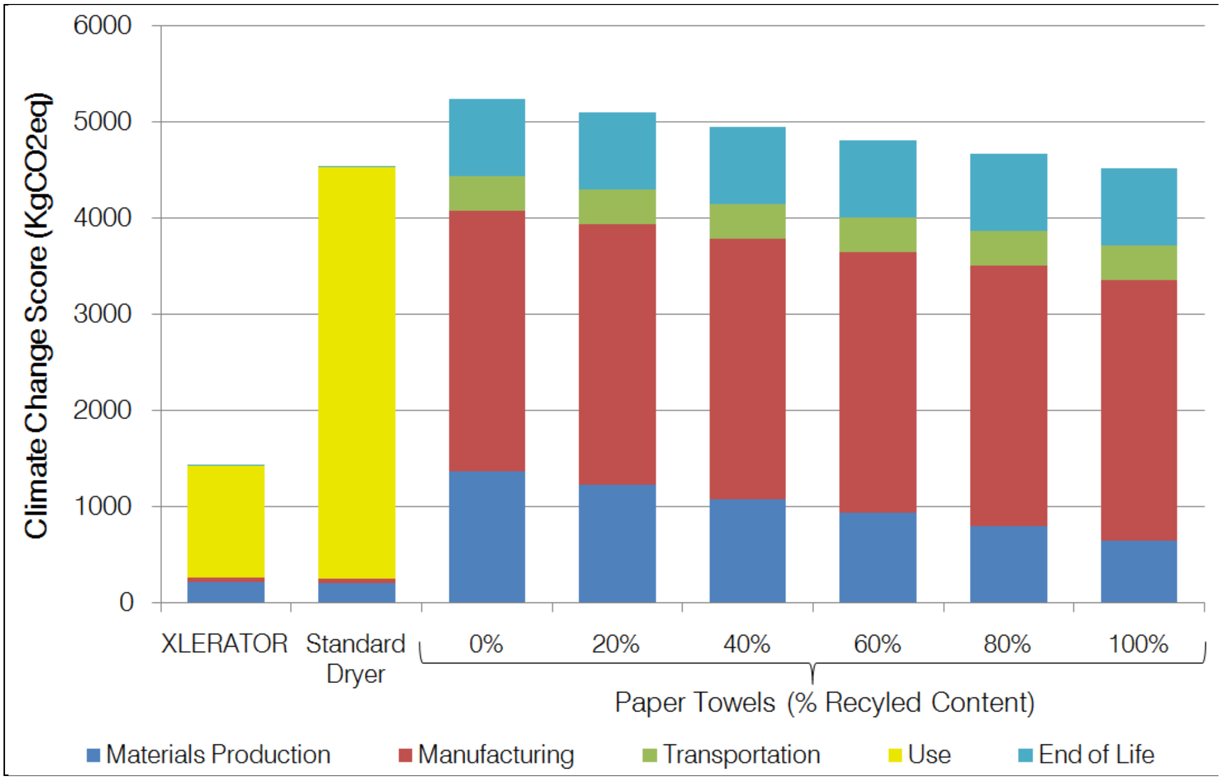

Figure 9: Climate change score for paper towels of varying recycled content, in comparison to the XLERATOR and the conventional electric hand dryer

Although increasing recycled content is shown as improving the performance of the recycled towel system, even at maximal recycled content, the climate change score for paper towels remains 220% above the impacts of the XLERATOR hand dryer system.

For all other indicators examined in this study, the XLERATOR system performs better than paper towels for all recycled paper content values. Regarding the comparison of the paper towels with the conventional hand dryer, the trend shown in Figure 9 (paper towels showing a benefit for all percents of recycled content) holds true for all impact categories.

Allocation of Recycled Content

An alternate scenario was created to examine an alternate methodological choice for allocating impacts of the original pulp production in cases of using recycled content (see description in section 2.7 and in section 6.4). Whereas the baseline scenario allocates no production impacts and all end-of-life impacts/benefits to recycled content, the alternate scenarios allocate to the recycled content: half of production impacts and half of end-of-life impacts/benefits; and no impacts from pulp production, recycling and end-of-life. The results are shown in Figure 10.

As discussed in section 2.5, the baseline scenario for towels does not consider the impacts of forming recycled pulp from previously used paper products that have been collected and sorted due to a lack of data of suitable quality to characterize this process. However, a scenario has been run using information on the electricity use alone from Madsen (2007) and these results are also shown in Figure 10 for the case of 100% recycled content.

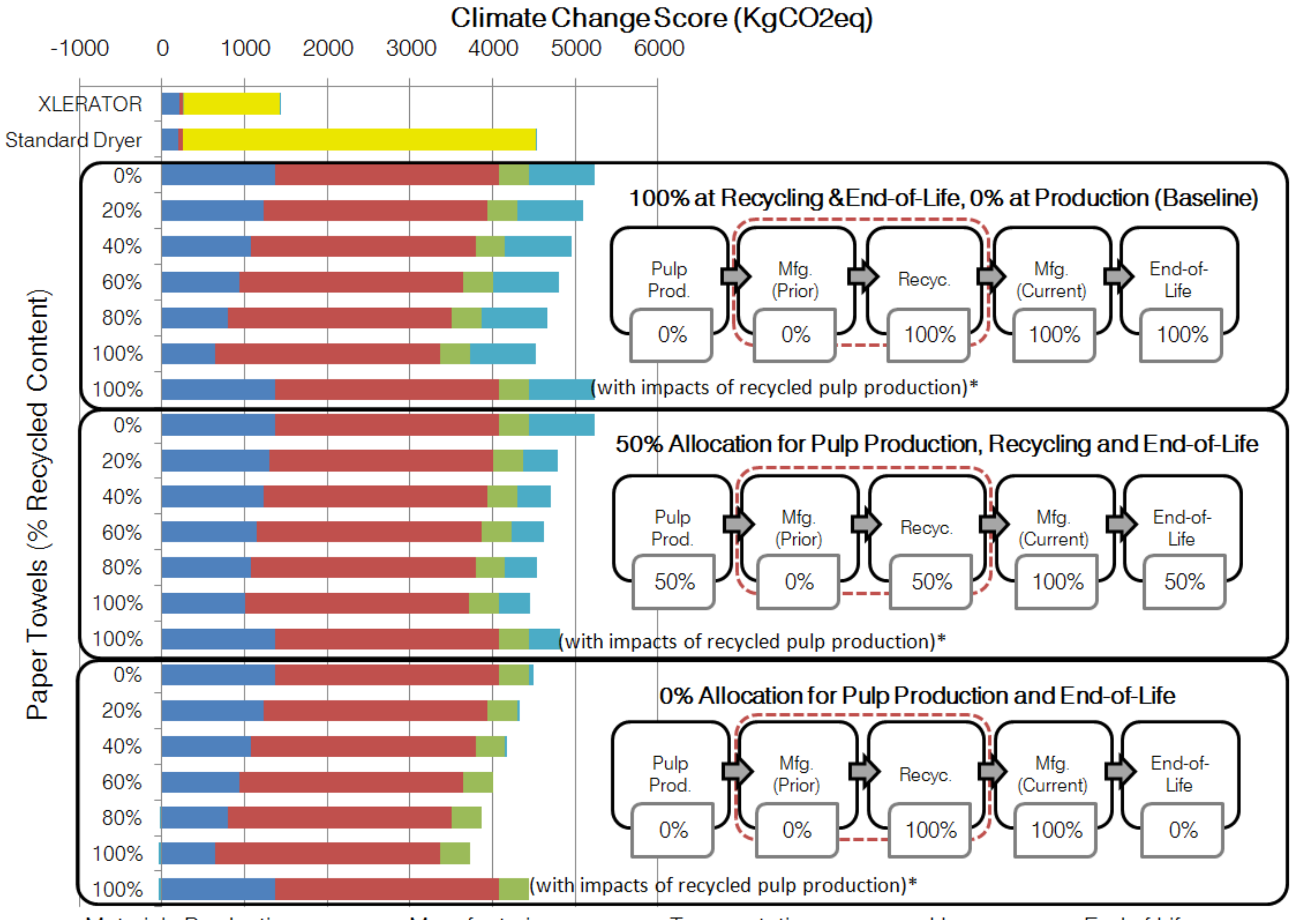

Figure 10: Climate change score for the paper towel system under varying allocation procedures for recycled content, in comparison to the XLERATOR and conventional hand dryer. (*= the production of recycled pulp from collected paper has been represented without any impacts in the baseline scenario due to lack of high-quality data. In these scenarios, a value for electricity used in this process from Madsen (2007) has been used to assess the potential importance of this omission.)

It is clear that the choice of allocation method is an important determinant in the result for the recycled content paper towels, showing a potential difference of as much as 20% in the total climate change score for the system. However, the difference resulting from alternative approaches for allocating these impacts are far too small to change the findings of the comparison, with the XLERATOR showing a much lesser impact even in the "best case" scenario for allocating impacts to the recycled content.

The scenarios in which the impacts of producing recycled pulp have been included suggest that including accurate data for this process might result in the loss of most or all benefit from the use of recycled content. Indeed, Madsen (2007) finds a slightly *higher* impact on all indicators they report for paper washroom towels with recycled content. Because of the direction of the effect of this omission, it does not have an effect on the conclusions of the study, but suggests that obtaining high-confidence data on this process is an important priority to understand the comparison between virgin and recycled content for paper towels.

Source of Electricity

While the baseline scenario assumes electricity for use of the electric hand dryers is being drawn from the average US electricity production, several additional scenarios were created to explore the sensitivity of results to this assumption. The alternative sources of electricity that were considered include only coal-derived electricity (the “consequential” approach) and only wind-derived electricity (to show an example of the potential improvement for the use of a renewable energy). The results are shown in Figure 11.

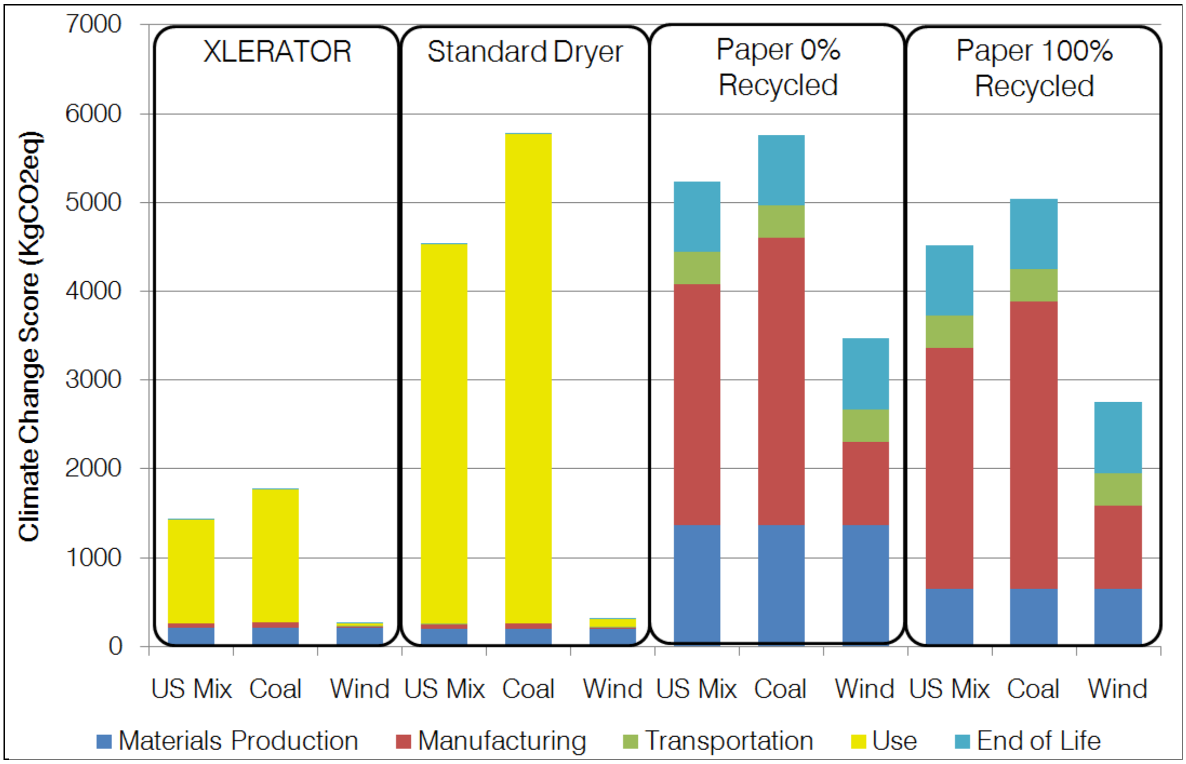

Figure 11: Climate change score for the hand drying systems under varying electricity sources during their use and production, in comparison to 0% recycled content and 100% recycled content towels

Because electricity consumption during the use of the hand dryers is the dominant contributor to the impact of the electric hand dryer systems, the choice of electricity and its representation in the LCA are highly important determinants of the results. As seen in Figure 11, the assumption that the electric hand dryers are using coal-derived electricity increases the impacts from these systems by between 20% and 30% in comparison with the average US electricity grid.

In the case that wind power is used to supply the use of the electric hand dryer systems, the impacts from the climate change score for these systems are dramatically reduced. The impacts for both systems are reduced to between 7% and 18% the impacts of the 100% recycled content towels, depending on the impact category in question. This suggests that the user of the electric hand dryers has a significant amount of control in determining the impacts of these systems if they are able to ensure that the electricity is from a renewable source. The towel systems show a similar directional trend with the substitution of coal or wind energy, but the changes are less extreme in either direction due to a lesser percent contribution of electricity production to the impact of these systems.

Intensity of Use

Both the electric hand dryer systems and the paper towel systems are subject to significant variation in the behavior of the user. Whereas the electric hand dryer user can take a longer or shorter time in drying his hands, the paper towel user can take multiple towels (or longer towels in the case of a continuous dispensing roll). As described above, multiple scenarios were created to examine the sensitivity of results to the behavior of the user. The results are show in Figure 12.

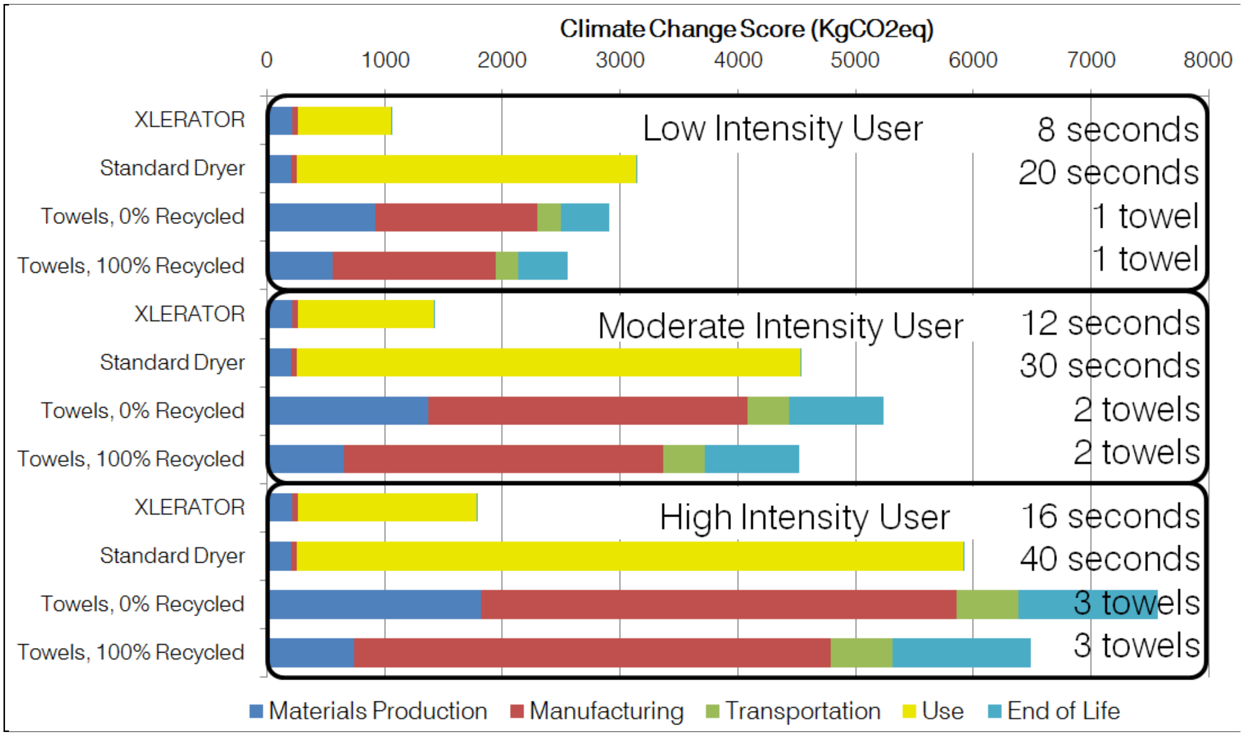

Figure 12: Variation in climate change score with varying intensities of use (dry time or number of towels)

It is clear from the scenario results that the behavior of the user has a very important influence on the overall impact. Within the scenarios examined, the variation is by far the largest for the towel systems due to the large variation between the low and high intensity assumptions (300%) for this system. The high intensity use rates for the conventional hand dryers and the XLERATOR represent increases over the low intensity rate of 100%.

3.4 Midpoint Impact Indicators

To provide additional information on the types of impacts within each system and to test the sensitivity of the results to the impact assessment method that has been used, we have evaluated the environmental impacts at each of the midpoint indicators under the IMPACT 2002+ system, as well as the TRACI impact assessment system. The results are shown in Figure 13.

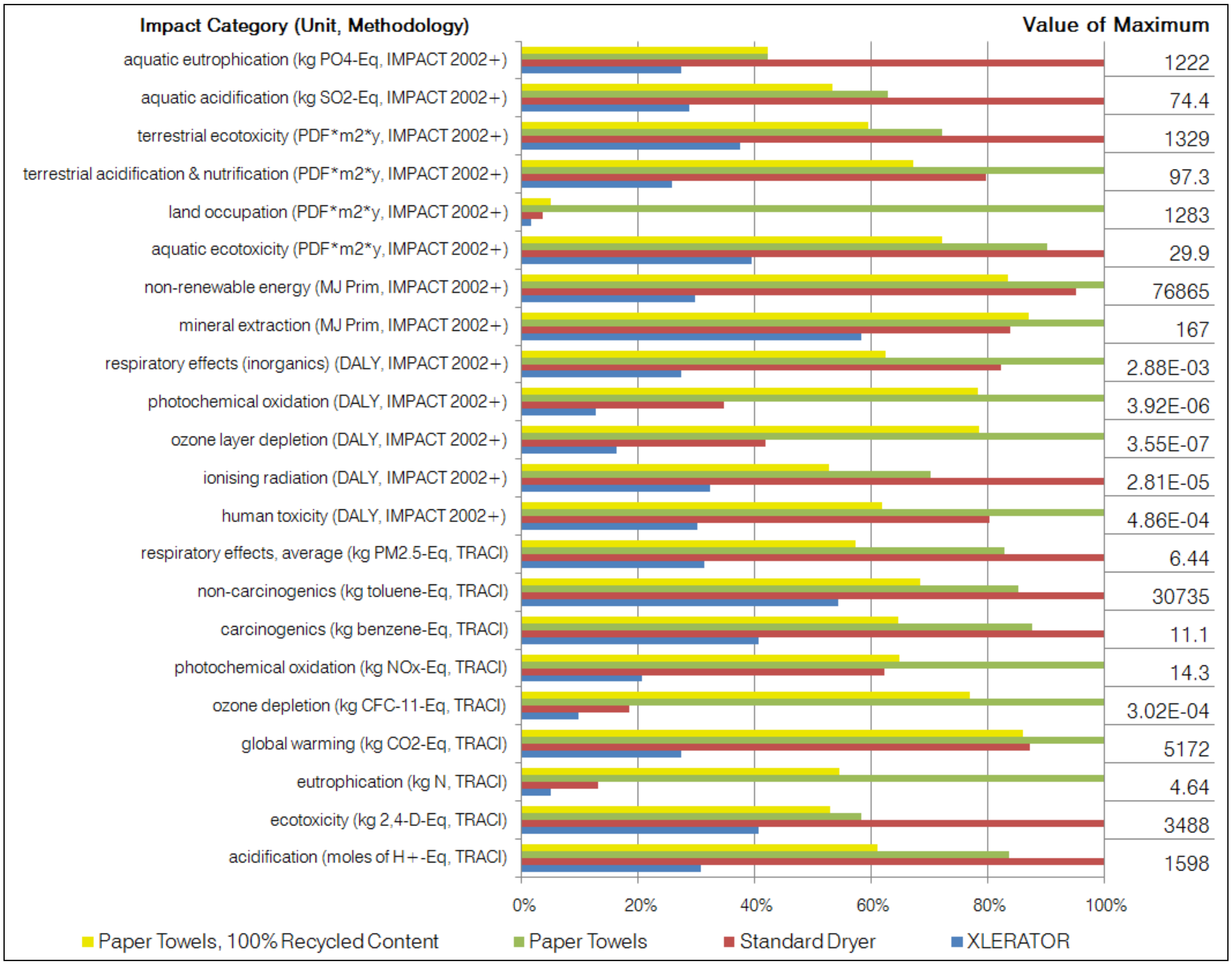

Figure 13: Impact assessment results at the midpoint level for the IMPACT 2002+ and TRACI impact assessment systems

For all midpoint indicators in both impact assessment methodologies, the XLERATOR is the lowest scoring of the systems evaluated. In all but two cases it is less than 60% of the most impacting system and in all but four cases it is less than 40% of the most impacting system. The paper towels and conventional electric hand dryer each are the most impacting system on approximately half of the indicators examined, further suggesting that the comparison between these two systems is of a very marginal difference. Comparison of similar impact categories among the two methodologies shows quite consistent results, for example in the cases of respiratory effects and human toxicity (carcinogenics and non-carcinogenics in TRACI). This confirms that the use of a European-based impact assessment method has not introduced a bias into the results.

3.5 Comparison with Prior Results

While this is the first LCA that we are aware of focusing on a high-efficiency hand dryer, both conventional electric hand dryers and paper towels have been studied previously in other contexts. Because the results of this study indicate a definitive advantage for the high-efficiency hand dryers, it is interesting to examine the results of other studies to check on the level of consistency. Figure 14 shows a comparison of the present results with two other studies. These studies were performed by the same consulting group and were sponsored by manufacturers of conventional hand dryers (Bobrick and Airdri,(Environmental

Resources Management 2001)) and paper towels (Kimberly Clark (Madsen 2007)). Both were used as references for some assumptions made in the present study.

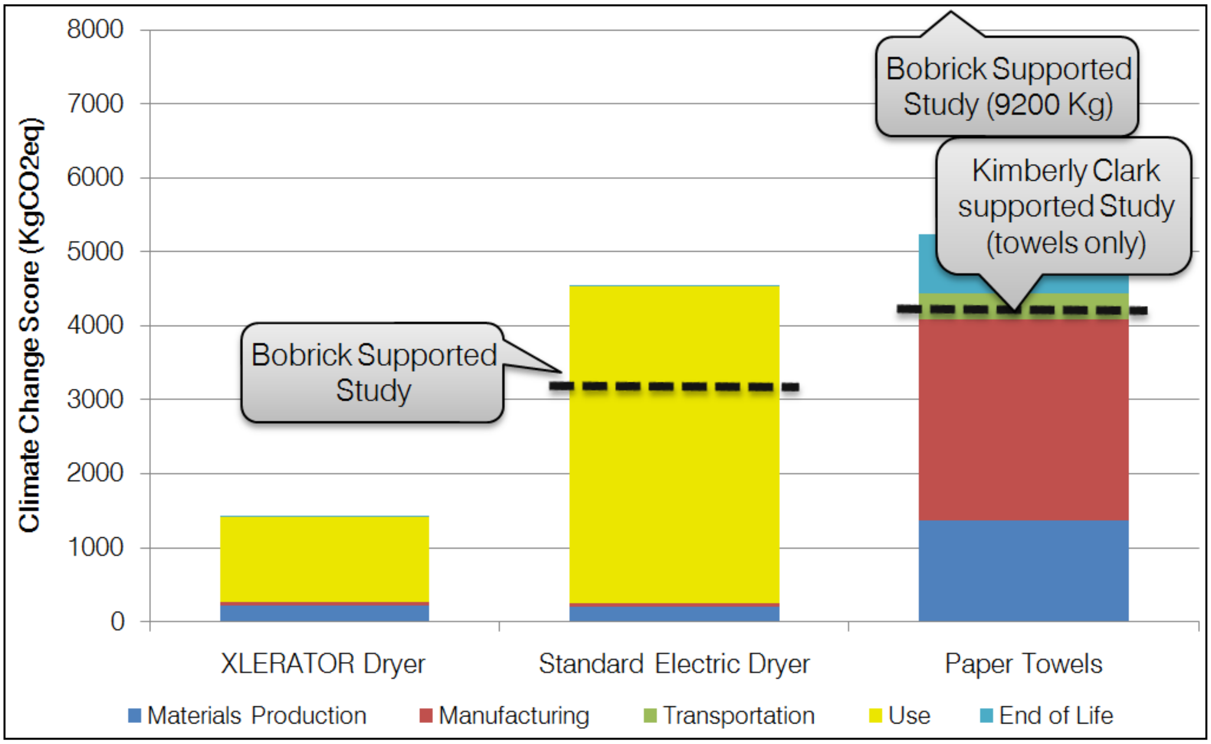

Figure 14: Comparison of the results of this study with those of similar systems studied elsewhere (numbers adjusted to the present study's functional unit; prior studies use differing Global Warming Potential systems)

Our current results clearly estimate a significantly higher impact for the conventional hand dryer and a lesser impact for paper towels than in the Bobrick/Airdri report. In comparison to both prior studies, the present report uses an updated Global Warming Potential system (IPCC 2007), which may explain a difference of 5 or 10%. Regarding the conventional electric hand dryers, a few assumptions in the present study are different than in the Bobrick/AirDri report. A lower wattage (2300 vs. 2400) has been assumed and additional energy use is assumed during a short time in which the drier shuts down. In total, these difference lead to a change of only a few percent in the energy used during the use phase of the conventional hand dryers. The apparent difference is in the range of 50%, leaving a substantial unexplained difference. It is clear that the great majority of this difference must be in the use phase of the hand dryer and it can therefore be traced to a difference in the assumed greenhouse gas emissions due to electricity consumption. The prior report does not disclose the numbers that have been used for this. For the US grid electricity used in this study, data from ecoinvent(The Ecoinvent Center 2007) has been used, resulting in a total GWP of 0.84 kg CO_2 equivalents per kilowatt-hour(see appendix).

At the time of the report to Bobrick/Airdri, the authors of that study had access to a variety of data on the impacts of paper and pulp production that showed a wide range of values. Sensitivity tests with a variety of data led to the average value shown in Figure 14, while the lowest value was approximately half that number. The Kimberly Clark report, produced by the same company several years later, benefited from both an improvement in the available data in the intervening years and direct access to a producer of the product, allowing the revised number shown in Figure 14. That value is within about 20% of the estimate produced here, some of which might be explained by the update to the GWP methodology. An additional amount of the difference might be explained by the use of the ecoinvent 2.01 in this study, while the prior study used version 1 for some wood, pulp and paper data, modifying it with data taken directly from their client. Further, the Kimberly Clark study includes only the towels, while we have also included the dispenser, waste bin and liner bags (together, these other components contribute 7% to the climate change score). Given these differences, the agreement seen with this study is quite good.

Both prior studies examined put the impacts of the respective systems in the range of 3,000 to 4,500 kg CO_2 equivalents for the functional unit used here (260,000 dries). The present results give a climate change score for the XLERATOR that is less than half of the number found by these other studies.

3.6 Study Limitations

Section 6.5 contains a summary of our assessment of the quality and consistency of information used to support the results shown here. Overall, the quality of the information is sufficient to meet the goals of the study and the consistency of treatment among the systems studied is quite good.

There are several limitations in the current study that should be reiterated and that might be made a focus of future work in examining such systems. The most significant limitation is likely to be the lack of complete and transparent information on the process of producing recycled pulp from used paper. An additional area of inadequate data is regarding the impacts of disposing of batteries. Both of these uncertainties are likely to result in greater impacts of the paper systems (only of the recycled paper systems in the case of the recycling process) if fully accounted for. They would therefore not change the direction of the conclusion regarding the XLERATOR and paper towels systems, but rather would enforce it. While they might provide an additional advantage to the conventional hand dryer in comparison to the paper systems, it is unlikely that they would result in a difference among these systems that was beyond the range of variation caused by differences in manufacturing and use of the systems.

It is discussed in section 2.4 that there is a potential for an interaction among the electric hand dryers and the heating/cooling systems of building where the heat produced by the hand dryers may results in a greater or lesser use of energy in heating and cooling, depending on whether the building is being heated or cooled at the time of use. The present study is unable to address this issue explicitly, as it would require detailed information on the average conditions for the buildings in which the units are being used, as well as detailed information about their HVAC systems, which are clearly beyond the scope of the present assessment. It is assumed that building heating and cooling roughly balance each other out, then this effect would become negligible.

Effort has been made here to make the calculations of life cycle impacts as representative of US conditions as possible. The results may therefore not be directly applicable in other geographies. It can be said that because the majority of the impacts of the electric hand dryer systems are from use of electricity, application of these technologies in countries with a less impacting electrical production would likely result in a decrease in environmental impacts for those systems. Nevertheless, a full assessment would be warranted to apply the results for a valid comparison in other geographies.

Section 6.6 shows the results of a statistical uncertainty assessment that has been conducted on the results.

4 Conclusions

The purpose of the present study is to investigate the differing environmental impacts originating from various options for drying of hands in public buildings. It is clear from the results that the high-efficiency hand dryer system, the XLERATOR, shows a significant advantage in its environmental impacts in comparison to the conventional electric hand dryer s or to paper towels. The comparison among conventional electric hand dryers and paper towels systems is within a close enough range to be highly influenced by the specific product and use characteristics and the assumptions of the study.

The results show that the great majority of environmental impact occurring during the life cycle of the electric hand dryer systems occurs during the use phase of these products. In contrast, the paper towel system is dominated by the production of raw materials and manufacture of the towels. Transportation is of moderate importance for the towel systems (between 3 and 20%, depending on impact category), while of very little importance for the electric hand dryers (less than 1%). End-of-life is important for the climate change score of towels, where methane emissions from landfills contribute as much as 20% of the total. End-of-life is of much lesser importance for the other impact categories and for the electric hand dryer systems. Within the towel system, it is the towels themselves, rather than the dispenser, waste bin, batteries or bin liners that are responsible for the majority of life cycle impacts (>90%).

The sensitivity and uncertainty tests that have been conducted indicate that the environmental advantage of the XLERATOR has very little dependence on the assumptions of the study or conditions of use. The allocation methodology for recycled content that has been applied here leads to results that suggest a slight improvement in the towel system when recycled content is used However, even in the “best case” allocation methodology applied as a sensitivity test, the improvement from incorporation of 100% recycled content is not sufficient to reduce the environmental impact to near the level of the XLERATOR and a sensitivity test regarding the impacts of producing recycled pulp suggests that there may be very little, if any, benefit from using recycled content in paper towels. The uncertainty assessment shows a high level of confidence that the advantage of the XLERATOR system, with the probability of error at less than one in one million.

Scenarios that were generated to represent different types of users suggest that the intensity of use is a very important factor, with impacts increasing in a nearly proportional fashion with the time the hand dryer is used or the number of towels that are used. Although the results vary substantially for various use profiles, even the “high intensity” XLERATOR user remains at a lower level of environmental impact than the “low intensity” user for the conventional electric hand dryer and paper towel systems.

To test both the importance of the methodological choice of the study regarding electricity and the potential for improvements in either system from the use of renewable energy (using wind power as an example), sensitivity tests were conducted on the source of electricity. If one were to assume that coal is the source of electricity (rather than the average source within the US grid), the impacts of the electric hand dryer systems increase by approximately 25%. However, the paper towel systems use approximately 80% as much electricity over their lifecycle as the XLERATOR and so this change in methodology does very little to change the comparison between the XLERATOR and paper towel systems.

A change to wind-power for both use and production of the electric hand dryers and towels suggests a significant improvement for both systems. For both electric hand dryers, the impacts are reduced dramatically under this scenario (climate change score is reduced by between 80% and 95%), while for the paper towels, a reduction of about one-third is seen. For the electric hand dryer systems, these results suggest a potential for those building managers who purchase certified renewable energy to significantly reduce the impact of hand drying; the XLERATOR with wind energy is clearly the best option examined in this study. For the paper towel system, this result suggests that use of renewable energy or significant improvements in energy efficiency would significantly improve the performance of paper towel systems, but would not achieve a reduction to the level of the XLERATOR.

Assessment of a wide variety of midpoint-level environmental indicators under multiple methodology confirms that the XLERATOR is the lowest scoring system on each criteria evaluated, often by a wide margin. Evaluation of both a North American and European impact assessment methodology has assured that the results are representative of North American conditions.

The results of this study suggest a clear advantage for the XLERATOR high-efficiency electric hand dryer and suggest that the advantage is significant enough that there are few, if any, options for paper-based systems to improve adequately to compete with this new generation of electric hand dryers on environmental performance. Whereas previous LCA research has led to inconclusive or contradictory results regarding the relative advantages of electric or paper systems for drying hands, high-efficiency hand dryers, such as the XLERATOR, have established a definitive advantage in environmental performance.

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6 Appendices

6.1 Overview of Results

Table 2: Overview of results for the six environmental categories studied.

(Blue shadings indicate relative value within that system; Red shadings indicate relative value of totals among systems)

	Climate Change Score (Kg CO2 Eq.)		Resource Depletion Impact (MJ)		Water Use (US Person-Days)		Human Health Impact (DALYs)		Ecosystem Quality Impact (PDFs)	
	XLERATOR									
Materials Production	212.2	14.9%	3486	15.1%	19.63	21.0%	0.0002199	23.3%	181.5	32.6%
Manufacturing	48.04	3.4%	803.4	3.5%	2.30	2.5%	0.0000231	2.4%	11.71	2.1%
Transportation	4.65	0.3%	77.8	0.3%	0.08	0.1%	0.0000053	0.6%	1.71	0.3%
Use	1156	81.3%	18725	81.1%	71.65	76.5%	0.0006963	73.7%	361.4	65.0%
End of Life	0.54	0.0%	-5.4	0.0%	-0.02	0.0%	0.0000002	0.0%	-0.11	0.0%
Total	1422		23087		93.65		0.0009448		556.2	
	Standard Dryer									
Materials Production	202.4	4.5%	3258.9	4.4%	20.75	7.2%	0.0001880	6.7%	133.4	9.0%
Manufacturing	47.85	1.1%	801.1	1.1%	2.30	0.8%	0.0000231	0.8%	11.70	0.8%
Transportation	3.23	0.1%	54.0	0.1%	0.06	0.0%	0.0000037	0.1%	1.18	0.1%
Use	4276	94.4%	69247	94.4%	265.0	92.0%	0.0025750	92.3%	1336	90.1%
End of Life	0.26	0.0%	-1.2	0.0%	-0.02	0.0%	0.0000003	0.0%	0.33	0.0%
Total	4530		73359		288.06		0.0027901		1483	
	Paper Towels (0% Recycled Content)									
Materials Production	1367	26.1%	26902	34.9%	96.64	45.2%	0.0017784	52.1%	1680	70.9%
Manufacturing	2711	51.8%	45929	59.6%	116.4	54.5%	0.0011892	34.9%	595.0	25.1%
Transportation	360.9	6.9%	6036	7.8%	6.47	3.0%	0.0004178	12.2%	131.98	5.6%
Use	0.00	0.0%	0.0	0.0%	0.00	0.0%	0.0000000	0.0%	0.00	0.0%
End of Life	798.7	15.2%	-1829.4	-2.4%	-5.93	-2.8%	0.0000260	0.8%	-36.15	-1.5%
Total	5238		77038		213.62		0.0034114		2371	
	Paper Towels (100% Recycled Content)									
Materials Production	694.3	15.0%	15839	23.9%	51.71	29.6%	0.0004904	23.2%	267.8	28.1%
Manufacturing	2711	58.5%	45887	69.4%	116.4	66.8%	0.0011892	56.3%	595.0	62.4%
Trasportation	360.9	7.8%	6036	9.1%	6.47	3.7%	0.0004178	19.8%	132.0	13.9%
Use	0.00	0.0%	0.0	0.0%	0.00	0.0%	0.0000000	0.0%	0.00	0.0%
End of Life	870.3	18.8%	-1614.7	-2.4%	-0.22	-0.1%	0.0000154	0.7%	-41.97	-4.4%
Total	2326		40748		111.46		0.0012797		581.0	

6.2 Reference Flows

Table 3: Life cycle inventory processes used in this study, with description of data source, units, and total impacts per unit for the impact categories studied.

Description of Process / Material	Data Source[2]	Unit	IPCC 2007 GWP (Kg CO2 Eq.)	IMPACT 2002+ Human Health (DALYs)	IMPACT 2002+ Ecosystem Quality (PDFs)	IMPACT 2002+ Resource Depletion (MJ)	Water Use (only turbined, L)	Water Use (excluding turbined, L)
Natural gas, burned in industrial furnace low-NOx >100kW	Ecoinvent 2.01	MJ	0.07	0.00	0.00	1.29	0.12	21.15
Electricity, low voltage, at grid (US)	Ecoinvent 2.01	kWh	0.84	0.00	0.26	13.56	29.58	3217
Transport, lorry 20-28t, fleet average	Ecoinvent 2.01	tkm	0.19	0.00	0.07	3.24	1.40	222
Transport, transoceanic freight ship	Ecoinvent 2.01	tkm	0.01	0.00	0.00	0.17	0.09	13.2
Sulphate pulp, average, at regional storage	Ecoinvent 2.01	kg	0.80	0.00	1.36	13.44	95.40	2951
Disposal, paper, 11.2% water, to sanitary landfill	Ecoinvent 2.01	kg	1.02	0.00	0.01	0.45	0.48	158
Paper incineration: with energy recovery	Ecoinvent 2.01, adapted	kg	-0.49	0.00	-0.10	-8.34	-11.41	-1499
LDPE, extruded to film	Ecoinvent 2.01, adapted	kg	2.62	0.00	0.16	89.11	106.12	2752
Disposal, polyethylene, to sanitary landfill	Ecoinvent 2.01	kg	0.11	0.00	0.01	0.32	0.35	29.19
Battery D	IDEMAT 2001, adjusted to D from AA	unit	0.47	0.00	0.05	9.77	0.00	6.22
Corrugated board, fresh fibre, single wall, at plant	Ecoinvent 2.01	kg	1.00	0.00	1.24	15.21	68.21	5172
LDPE incineration: with energy recovery	Ecoinvent 2.01, adapted	kg	1.41	0.00	-0.39	-26.54	-38.99	-4786
Cardboard - recycling: net impacts	Ecoinvent 2.01, adapted	kg	-0.03	0.00	-0.61	-0.15	-45.30	-3329
Steel, converter, chromium steel 18/8, at plant	Ecoinvent 2.01	kg	5.18	0.00	5.56	88.08	88.93	59428
Disposal, packaging cardboard, to sanitary landfill	Ecoinvent 2.01	kg	1.31	0.00	0.01	0.43	0.46	141
Disposal, steel, to inert material landfill	Ecoinvent 2.01	kg	0.01	0.00	0.00	0.20	0.20	7.96
Zinc, primary, at regional storage	Ecoinvent 2.01	kg	3.41	0.00	22.85	52.21	139.21	70441
Disposal, steel, 0% water, to municipal	Ecoinvent 2.01	kg	0.02	0.00	0.01	0.34	1.28	19.99

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[2] Data listed as adapted from the ecoinvent database indicates data were combined from that source to produce representative data for this study. Those waste disposal categories listed as "net impacts" apply a system expansion approach to account for the recovery of material or energy and end-of-life recycling or waste-to-energy events. Energy recovery from waste-to-energy is assumed to achieve 10% of heat content as electricity and 20% as heat energy. Recycled materials are represented through a "closed loop approximation" in which the impacts of original production are credited back to the system when recycling occurs.

Description of Process / Material	Data Source[2]	Unit	IPCC 2007 GWP (Kg CO2 Eq.)	IMPACT 2002+ Human Health (DALYs)	IMPACT 2002+ Ecosystem Quality (PDFs)	IMPACT 2002+ Resource Depletion (MJ)	Water Use (only turbined, L)	Water Use (excluding turbined, L)
incineration								
Cardboard, with printing, from primary materials	Ecoinvent 2.01, adapted	kg	1.27	0.00	1.30	20.19	77.53	7314
Glass fibre reinforced plastic, polyamide, injection moulding, at plant	Ecoinvent 2.01	kg	8.76	0.00	0.36	148.21	602.65	6221
Disposal, plastics, mixture, to sanitary landfill	Ecoinvent 2.01	kg	0.09	0.00	0.01	0.33	0.36	34.17
Plastic mixture, with extrusion	Ecoinvent 2.01, adapted	kg	3.65	0.00	0.34	89.62	151.32	3538
Steel, with formation to product	Ecoinvent 2.01, adapted	kg	2.22	0.00	1.02	39.76	66.43	9950
Cardboard - incineration: net impacts	Ecoinvent 2.01, adapted	kg	-0.58	0.00	-0.14	-9.76	-13.05	-1727
Disposal, aluminium, 0% water, to sanitary landfill	Ecoinvent 2.01	kg	0.02	0.00	0.32	0.53	0.55	131
Sealing tape, aluminum/PE, 50 mm wide, at plant	Ecoinvent 2.01	m	0.24	0.00	0.05	4.60	7.19	1701
Disposal, municipal solid waste, to sanitary landfill	Ecoinvent 2.01	kg	0.54	0.00	0.01	0.40	0.44	107
Aluminum, with formation, from primary materials	Ecoinvent 2.01, adapted	kg	15.58	0.00	4.07	215.22	374.32	379840
Aluminum, with formation, produced from secondary	Ecoinvent 2.01, adapted	kg	4.73	0.00	2.60	73.99	123.49	63070
Plastic mixture incineration: with energy recovery	Ecoinvent 2.01, adapted	kg	1.02	0.00	-0.32	-21.70	-30.33	-3845
Copper, primary, at refinery	Ecoinvent 2.01	kg	5.43	0.00	43.99	138.26	325.25	186360
Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	Ecoinvent 2.01	kg	3.86	0.00	0.08	98.49	150.29	72.07
Electronic component, active, unspecified, at plant	Ecoinvent 2.01	kg	738.78	0.00	436.76	11916.50	22643.52	3773700
Disposal, steel, 0% water, to inert material landfill	Ecoinvent 2.01	kg	0.01	0.00	0.00	0.20	0.20	7.96
Disposal, zinc in car shredder residue, 0% water, to municipal incineration	Ecoinvent 2.01	kg	0.28	0.00	0.12	2.71	6.41	729
Disposal, aluminium, 0% water, to municipal incineration	Ecoinvent 2.01	kg	0.03	0.00	0.02	0.72	1.63	39.8

Description of Process / Material	Data Source[2]	Unit	IPCC 2007 GWP (Kg CO2 Eq.)	IMPACT 2002+ Human Health (DALYs)	IMPACT 2002+ Ecosystem Quality (PDFs)	IMPACT 2002+ Resource Depletion (MJ)	Water Use (only turbined, L)	Water Use (excluding turbined, L)
Disposal, municipal solid waste, 22.9% water, to municipal incineration	Ecoinvent 2.01	kg	0.50	0.00	0.02	0.43	1.96	79.00
Electroplating Chrome I	IDEMAT 2001	m2	2.76	0.00	0.16	34.30	25.30	0.00
Disposal, wood untreated, to municipal incineration, net benefits	Ecoinvent 2.01	kg	-0.59	0.00	-0.15	-9.96	-13.93	-1793
disposal, hazardous waste, 25% water, to hazardous waste incineration	Ecoinvent 2.01	kg	1.88	0.00	0.17	14.06	31.66	2159
disposal, hazardous waste, 0% water, to underground deposit	Ecoinvent 2.01	kg	0.18	0.00	0.05	2.91	2.73	239
Corrugated board, recycled fibre, single wall, at plant	Ecoinvent 2.01	kg	1.00	0.00	0.49	15.21	12.54	954
Nylon 6, at plant	Ecoinvent 2.01	kg	9.21	0.00	0.15	124.67	184.68	27.05
Ceramic tiles, at regional storage	Ecoinvent 2.01	kg	0.82	0.00	0.23	15.12	15.33	3334
LLDPE - incineration: net impacts	Ecoinvent 2.01, adapted	kg	1.41	0.00	-0.39	-26.54	-38.99	-4786
Polyethylene, LDPE, granulate, at plant	Ecoinvent 2.01	kg	2.09	0.00	0.03	79.72	47.04	9.67
Disposal, copper, to municipal incineration	Ecoinvent 2.01	kg	0.03	0.00	0.01	0.60	1.52	33.66
Disposal, wood, untreated, to sanitary landfill	Ecoinvent 2.01	kg	0.07	0.00	0.01	0.32	0.35	29.01
Epoxy resin, liquid, at plant	Ecoinvent 2.01	kg	6.73	0.00	0.26	137.72	403.41	46.11
Chromium, at regional storage	Ecoinvent 2.01	kg	26.73	0.00	8.27	469.41	632.53	1291200
Nickel, 99.5%, at plant	Ecoinvent 2.01	kg	11.22	0.00	32.03	176.29	392.63	428660
Sawn timber, softwood, planed, kiln dried, at plant	Ecoinvent 2.01	m3	104.23	0.00	375.76	1937.09	2792.64	512740
electricity, hard coal, at power plant	Ecoinvent 2.01	kWh	1.08	0.00	0.34	12.39	38.26	185.40
electricity, at wind power plant	Ecoinvent 2.01	kWh	0.02	0.00	0.01	0.30	0.67	110.41
Recycled Pulp Production and EOL Paper Collection	Ecoinvent 2.01, adapted	kg	0.13	0.00	0.02	1.54	0.86	399.44

Table 4: Life cycle inventory data used in this study, with the amount of each process or material accounted for in the full life cycle of each system.

Description of Process / Material	Unit	XLERATOR	Conventional hand dryer	Paper Towels (0% Recycled)	Paper Towels (100% Recycled)
Natural gas, burned in industrial furnace low-NOx >100kW	MJ	165.8	165.8	12838	12837
Electricity, low voltage, at grid (US)	kWh	1425	5151	2164	2164
Transport, lorry 20-28t, fleet average	tkm	23.27	15.91	1770.2	1770
Transport, transoceanic freight ship	tkm	14.26	14.61	1768.2	1768
Sulphate pulp, average, at regional storage	kg			1069.2	
Disposal, paper, 11.2% water, to sanitary landfill	kg			823.7	823
Paper incineration: with energy recovery	kg			205.9	205
LDPE, extruded to film	kg	0.0458		86.04	86.03
Disposal, polyethylene, to sanitary landfill	kg	0.01		68.83	68.82
Battery D	unit			40.00	40
Corrugated board, fresh fibre, single wall, at plant	kg	0.1145	0.4484	49.91	49.9
LDPE incineration: with energy recovery	kg			17.21	17.2
Cardboard - recycling: net impacts	kg	0.1182	0.2314	28.04	28.04
Steel, converter, chromium steel 18/8, at plant	kg	2.944		6.409	6.409
Disposal, packaging cardboard, to sanitary landfill	kg	0.0222	0.1736	21.04	21.04
Disposal, steel, to inert material landfill	kg	3.1770	2.835	4.96	4.96
Zinc, primary, at regional storage	kg	2.136	0.4888		
Disposal, steel, 0% water, to municipal incineration	kg	0.367	0.7088	1.2400	1.24
Cardboard, with printing, from primary materials	kg			4.4484	4.448
Glass fibre reinforced plastic, polyamide, injection moulding, at plant	kg	1.2205			
Disposal, plastics, mixture, to sanitary landfill	kg	0.9777	0.2254	2.0840	2.084
Plastic mixture, with extrusion	kg	0.3793		2.7781	2.778
Steel, with formation to product	kg		3.0553		
Cardboard - incineration: net impacts	kg	0.0887	0.0434	5.2607	5.26
Disposal, aluminium, 0% water, to sanitary landfill	kg		1.5489		
Sealing tape, aluminum/PE, 50 mm wide, at plant	m	1.0100			
Disposal, municipal solid waste, to sanitary landfill	kg				
Aluminum, with formation, from primary materials	kg		0.8514		
Aluminum, with formation, produced from secondary	kg		0.8514		
Plastic mixture incineration: with energy recovery	kg	0.2444	0.0564	0.5210	0.521
Copper, primary, at refinery	kg	0.2941	0.2333	0.1471	0.147
Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	kg	0.4917	0.1232		
Electronic component, active, unspecified, at plant	kg	0.2346	0.2346	0.2346	0.235
Disposal, steel, 0% water, to inert material landfill	kg	3.1770	2.8353	4.9600	4.96
Disposal, zinc in car shredder residue, 0% water, to	kg	0.4272			

Description of Process / Material	Unit	XLERATOR	Conventional hand dryer	Paper Towels (0% Recycled)	Paper Towels (100% Recycled)
municipal incineration					
Disposal, aluminium, 0% water, to municipal incineration	kg		0.3406		
Disposal, municipal solid waste, 22.9% water, to municipal incineration	kg				
Electroplating Chrome I	m2	0.0673			
Disposal, wood untreated, to municipal incineration, net benefits	kg		0.1535		
disposal, hazardous waste, 25% water, to hazardous waste incineration	kg			0.2400	0.24
disposal, hazardous waste, 0% water, to underground deposit	kg			0.9600	0.96
Corrugated board, recycled fibre, single wall, at plant	kg	0.1145			
Nylon 6, at plant	kg		0.1040		
Ceramic tiles, at regional storage	kg		0.0919		
LLDPE - incineration: net impacts	kg	0.0550			
Polyethylene, LDPE, granulate, at plant	kg		0.0545		
Disposal, copper, to municipal incineration	kg		0.0467		
Disposal, wood, untreated, to sanitary landfill	kg		0.0384		
Epoxy resin, liquid, at plant	kg	0.0076			
Chromium, at regional storage	kg	0.0048			
Nickel, 99.5%, at plant	kg	0.0017			
Sawn timber, softwood, planed, kiln dried, at plant	m3		0.00027		
electricity, hard coal, at power plant	kWh				
electricity, at wind power plant	kWh				
Recycled Pulp Production and EOL Paper Collection	kg				1069

Table 5: Results of life cycle impact assessment for each material or process represented in the foreground of the XLERATOR system

Category	*Sub-Category*	*Title*	*Climate Change Score (KgCO2eq)*	*Resources (MJ)*	*Human Health (DALY)*	*Ecosystem Quality (PDF*m2*y)*	*Freshwater Use (Person-days)*
1. Materials Production							
Cover	Zinc Cover	Zinc, primary, at regional storage	7.29	111.51	1.5E-05	48.800	2.192
Cover	Epoxy Paint	Epoxy resin, liquid, at plant	0.05	1.05	5.3E-08	0.002	0.001
Cover	Chrome Plating Nickel	Nickel, 99.5%, at plant	0.02	0.31	1.7E-07	0.056	0.011
Cover	Chrome Plating Chromium	Chromium, at regional storage	0.13	2.27	8.9E-08	0.040	0.089
Cover	Fiberglass Reinforced Resin	Glass fibre reinforced plastic, polyamide, injection moulding, at plant	10.69	180.88	4.1E-06	0.437	0.266
Cover	Brushed Stainless Steel	Steel, converter, chromium steel 18/8, at plant	9.49	161.24	1.8E-05	10.171	1.574
Air Outlet		Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.12	2.99	4.3E-08	0.002	0.001
Terminal Block		Plastic mixture, with extrusion	0.16	4.02	1.7E-07	0.015	0.004
Control Assembly / Sensor		Electronic component, active, unspecified, at plant	149.60	149.60	2413.00	1.3E-04	88.440
Heating Element (Ni-Chrome coil)		Steel, converter, chromium steel 18/8, at plant	0.33	0.33	5.65	6.4E-07	0.356
Motor Steel Content		Steel, converter, chromium steel 18/8, at plant	4.57	77.71	8.8E-06	4.902	0.758
Motor Copper Content		Copper, primary, at refinery	1.60	1.60	40.67	1.8E-05	12.939
Motor Plastics Content		Plastic mixture, with extrusion	1.01	1.07	26.36	1.1E-06	0.099
Wall Plate Assembly		Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	1.74	44.31	6.4E-07	0.035	0.015
Cover Brackets		Steel, converter, chromium steel 18/8, at plant	0.86	14.69	1.7E-06	0.926	0.143
Housing Grommets		Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.04	1.13	1.6E-08	0.001	0.000
Housing Retainer		Plastic mixture, with extrusion	0.15	3.61	1.6E-07	0.014	0.003
Optics Assembly		Electronic component, active, unspecified, at plant	23.69	382.15	2.1E-05	14.006	1.868
Molded Pulp End Caps		Corrugated board, recycled fibre, single wall, at plant	0.11	0.11	1.74	4.8E-08	0.057
Carton		Corrugated board, fresh fibre, single wall, at plant	0.11	1.74	1.1E-07	0.142	0.010
Carton Tape		Sealing tape, aluminum/PE, 50 mm wide, at plant	0.24	4.65	1.4E-07	0.055	0.026
Plastic Bag - Dryer		LDPE, extruded to film	0.06	2.04	2.4E-08	0.004	0.001
Plastic Bag - Wrench		LDPE, extruded to film	0.06	2.04	2.4E-08	0.004	0.001
1. Materials Production	Stage Total		212.20	3485.77	2.2E-04	181.504	19.634
2. Manufacturing							
Electricity		Electricity, low voltage, at grid (US)	36.24	586.81	2.2E-05	11.324	2.245
Natural Gas		Natural gas, burned in industrial furnace low-NOx >100kW	11.61	214.26	1.3E-06	0.373	0.054
Chrome Plating		Electroplating Chrome I	0.19	2.31	1.3E-09	0.011	0.000
2. Manufacturing	Stage Total		48.04	803.38	2.3E-05	11.708	2.300
3. Transportation							

Category	*Sub-Category*	*Title*	*Climate Change Score (KgCO2eq)*	*Resources (MJ)*	*Human Health (DALY)*	*Ecosystem Quality (PDF*m2*y)*	*Freshwater Use (Person-days)*
Inbound	Ship	Transport, transoceanic freight ship	0.00	0.00	3.7E-10	0.000	0.000
	Truck	Transport, lorry 20-28t, fleet average	1.38	23.09	1.5E-06	0.515	0.025
Outbound	Ship	Transport, transoceanic freight ship	0.15	2.39	3.4E-07	0.033	0.003
	Truck	Transport, lorry 20-28t, fleet average	2.75	46.18	3.0E-06	1.029	0.049
End of Life	Truck	Transport, lorry 20-28t, fleet average	0.37	6.16	4.0E-07	0.137	0.007
3. Transportation	Stage Total		4.65	77.82	5.3E-06	1.714	0.083
4. Use							
Electricity	Total Usage	Electricity, low voltage, at grid (US)	1156.34	18725.23	7.0E-04	361.356	71.653
4. Use	Stage Total		1156.34	18725.23	7.0E-04	361.356	71.653
5. End of Life							
Zinc Cover	Landfilled	Disposal, steel, to inert material landfill	0.01	0.34	1.6E-08	0.005	0.000
Zinc Cover	Incinerated	Disposal, zinc in car shredder residue, 0% water, to municipal incineration	0.12	1.16	2.1E-07	0.052	0.005
Steel Cover	Landfilled	Disposal, steel, to inert material landfill	0.01	0.29	1.4E-08	0.004	0.000
Steel Cover	Incinerated	Disposal, steel, 0% water, to municipal incineration	0.01	0.12	9.8E-08	0.003	0.000
Resin Cover	Landfilled	Disposal, plastics, mixture, to sanitary landfill	0.09	0.32	1.6E-08	0.006	0.001
Resin Cover	Incinerated	Plastic mixture incineration: with energy recovery	0.25	-5.30	-6.6E-08	-0.078	-0.015
Plastics	Landfilled	Disposal, plastics, mixture, to sanitary landfill	0.00	0.00	2.2E-11	0.000	0.000
Plastics	Incinerated	Plastic mixture incineration: with energy recovery	0.00	-0.01	-8.9E-11	0.000	0.000
Other Metals	Landfilled	Disposal, steel, to inert material landfill	0.00	0.00	3.6E-11	0.000	0.000
Other Metals	Incinerated	Disposal, steel, 0% water, to municipal incineration	0.00	0.00	2.6E-10	0.000	0.000
Cardboard	Recycled	Cardboard - recycling: net impacts	0.00	-0.02	-5.1E-08	-0.073	-0.007
Cardboard	Incinerated	Disposal, packaging cardboard, to sanitary landfill	0.03	0.01	7.0E-10	0.000	0.000
Cardboard	Landfilled	Cardboard - incineration: net impacts	-0.05	-0.87	1.2E-09	-0.013	-0.002
Plastic	Incinerated	Disposal, polyethylene, to sanitary landfill	0.00	0.00	2.3E-10	0.000	0.000
Plastic	Landfilled	LLDPE - incineration: net impacts	0.08	-1.46	-2.4E-08	-0.022	-0.004
5. End of Life	Stage Total		0.54	-5.40	2.1E-07	-0.115	-0.022
	Grand Total		**1422**	**23087**	**9.4E-04**	**556.2**	**93.65**

Table 6: Results of life cycle impact assessment for each material or process represented in the foreground of the conventional electric hand dryer system

Category	*Sub-Category*	*Title*	*Climate Change Score (KgCO2eq)*	*Resources (MJ)*	*Human Health (DALY)*	*Ecosystem Quality (PDF*m2*y)*	*Freshwater Use (Person-days)*
1. Materials Production							
Galvanized Steel		Steel, with formation to product	4.26	76.30	3.6E-06	1.956	0.297

Non-Galvanized Steel		Steel, with formation to product	4.25	2.52	45.18	2.2E-06	1.158
Recycled Aluminum		Aluminum, with formation, produced from secondary	4.03	63.00	2.6E-06	2.214	0.782
Virgin Aluminum		Aluminum, with formation, from primary materials	13.27	183.25	1.0E-05	3.466	4.642
Zinc		Zinc, primary, at regional storage	1.67	25.52	3.5E-06	11.169	0.502
Cardboard		Corrugated board, fresh fibre, single wall, at plant	0.45	6.82	4.2E-07	0.556	0.039
Copper		Copper, primary, at refinery	1.27	32.26	1.4E-05	10.264	0.631
Wood		Sawn timber, softwood, planed, kiln dried, at plant	0.03	0.53	4.4E-08	0.102	0.002
Nylon		Nylon 6, at plant	0.96	12.97	3.3E-07	0.016	0.004
Ceramic		Ceramic tiles, at regional storage	0.08	1.39	6.0E-07	0.022	0.005
Polyethylene		Polyethylene, LDPE, granulate, at plant	0.11	4.35	4.3E-08	0.002	0.001
PBT		Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.16	3.98	5.8E-08	0.003	0.001
Optics Assembly		Electronic component, active, unspecified, at plant	23.69	382.15	2.1E-05	14.006	1.868
Control Assembly / Sensor		Electronic component, active, unspecified, at plant	149.60	149.60	2413.00	1.3E-04	88.440
Other		Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	0.32	8.16	1.2E-07	0.007	0.003
1. Materials Production	Stage Total		202.41	3258.85	1.9E-04	133.380	20.747
2. Manufacturing							
Electricity		Electricity, low voltage, at grid (US)	36.24	586.81	2.2E-05	11.324	2.245
Natural Gas		Natural gas, burned in industrial furnace low-NOx >100kW	11.61	214.26	1.3E-06	0.373	0.054
2. Manufacturing	Stage Total		47.85	801.07	2.3E-05	11.697	2.299
3. Transportation							
Inbound	Ship	Transport, transoceanic freight ship	0.05	0.82	1.2E-07	0.011	0.001
	Truck	Transport, lorry 20-28t, fleet average	0.94	15.79	1.0E-06	0.352	0.017
Outbound	Ship	Transport, transoceanic freight ship	0.10	1.64	2.3E-07	0.023	0.002
	Truck	Transport, lorry 20-28t, fleet average	1.88	31.58	2.1E-06	0.704	0.034
End of Life	Truck	Transport, lorry 20-28t, fleet average	0.25	4.21	2.8E-07	0.094	0.004
3. Transportation	Stage Total		3.23	54.03	3.7E-06	1.183	0.058
4. Use							
Electricity	Total Usage	Electricity, low voltage, at grid (US)	4276.18	69246.64	2.6E-03	1336.309	264.976
4. Use	Stage Total		4276.18	69246.64	2.6E-03	1336.309	264.976
5. End of Life							
Steel	Landfilled	Disposal, steel, to inert material landfill	0.02	0.48	2.3E-08	0.007	0.000
Steel	Incinerated	Disposal, steel, 0% water, to municipal incineration	0.01	0.20	1.6E-07	0.004	0.000
Aluminum	Landfilled	Disposal, aluminium, 0% water, to sanitary landfill	0.03	0.72	6.3E-08	0.438	0.003
Aluminum	Incinerated	Disposal, aluminium, 0% water, to municipal incineration	0.01	0.25	9.8E-08	0.006	0.000
Copper	Landfilled	Disposal, aluminium, 0% water, to sanitary landfill	0.00	0.10	8.6E-09	0.060	0.000
Copper	Incinerated	Disposal, copper, to municipal incineration	0.00	0.03	1.3E-08	0.001	0.000
Zinc	Landfilled	Disposal, steel, to inert material landfill	0.00	0.08	3.7E-09	0.001	0.000
Zinc	Incinerated	Disposal, steel, 0% water, to municipal incineration	0.00	0.03	2.6E-08	0.001	0.000

Plastics	Landfilled	Disposal, plastics, mixture, to sanitary landfill	0.01	0.05	2.7E-09	0.001	0.000
Plastics	Incinerated	Plastic mixture incineration: with energy recovery	0.04	-0.86	-1.1E-08	-0.013	-0.002
Cardboard	Recycled	Cardboard - recycling: net impacts	-0.01	-0.03	-9.9E-08	-0.142	-0.013
Cardboard	Landfilled	Disposal, packaging cardboard, to sanitary landfill	0.23	0.08	5.5E-09	0.001	0.000
Cardboard	Incinerated	Cardboard - incineration: net impacts	-0.02	-0.42	6.0E-10	-0.006	-0.001
Wood	Landfilled	Disposal, wood untreated, to municipal incineration	-0.09	-1.53	-1.4E-09	-0.023	-0.004
Wood	Incinerated	Disposal, wood, untreated, to sanitary landfill	0.00	0.01	6.2E-10	0.000	0.000
Other	Landfilled	Disposal, plastics, mixture, to sanitary landfill	0.01	0.02	1.1E-09	0.000	0.000
Other	Incinerated	Plastic mixture incineration: with energy recovery	0.02	-0.36	-4.5E-09	-0.005	-0.001
5. End of Life	Stage Total		0.26	-1.16	2.9E-07	0.332	-0.017
	Grand Total		**4530**	**73360**	**28000**	**1483**	**288.1**

Table 7: Results of life cycle impact assessment for each material or process represented in the foreground of the paper towel system

Category	*Sub-Category*	*Title*	*Climate Change Score (KgCO2eq)*	*Resources (MJ)*	*Human Health (DALY)*	*Ecosystem Quality (PDF*m2*y)*	*Freshwater Use (Person-days)*
1. Materials Production							
Towels	Virgin Pulp	Sulphate pulp, average, at regional storage	850.53	14366.95	1.4E-03	1450.800	66.602
Towels	Recycled Pulp	Sulfate Pulp Production and EOL Paper Collection	0.00	0.00	0.0E+00	0.000	0.000
Towels	Cardboard Packaging	Corrugated board, fresh fibre, single wall, at plant	48.90	743.79	4.6E-05	60.577	4.295
Liner	Bag	LDPE, extruded to film	225.01	7666.66	9.0E-05	13.655	5.316
Liner	Cardboard Packaging	Cardboard, with printing, from primary materials	5.29	84.20	4.6E-06	5.422	0.501
Dispenser	Dispenser housing	Plastic mixture, with extrusion	9.61	235.79	1.0E-05	0.889	0.217
Dispensor	Optics	Electronic component, active, unspecified, at plant	23.69	382.15	2.1E-05	14.006	1.868
Dispensor	Controls	Electronic component, active, unspecified, at plant	149.60	2413.00	1.3E-04	88.440	11.794
Dispensor	Motor - Copper	Copper, primary, at refinery	0.80	20.33	8.9E-06	6.469	0.398
Dispensor	Motor - Steel	Steel, converter, chromium steel 18/8, at plant	0.76	12.95	1.5E-06	0.817	0.126
Dispensor	Motor - Plastics	Plastic mixture, with extrusion	0.54	13.18	5.7E-07	0.050	0.012
Dispenser	Cardboard Packaging	Cardboard, with printing, from primary materials	0.25	3.98	2.2E-07	0.256	0.024
Waste Bin	Bin	Steel, converter, chromium steel 18/8, at plant	32.46	551.53	6.3E-05	34.790	5.382
Waste Bin	Cardboard Packaging	Corrugated board, fresh fibre, single wall, at plant	1.01	15.36	9.5E-07	1.251	0.089
Batteries	Batteries	Battery AA	18.93	390.87	2.0E-05	2.120	0.004
Batteries	Cardboard Packaging	Cardboard, with printing, from primary materials	0.10	1.61	8.8E-08	0.104	0.010
1. Materials Production	Stage Total		1367.48	26902.37	1.8E-03	1679.647	96.637
2. Manufacturing							
Dispensor	Electricity	Electricity, low voltage, at grid (US)	36.24	586.81	2.2E-05	11.324	2.245
Dispensor	Natural Gas	Natural gas, burned in industrial furnace low-NOx >100kW	11.61	214.26	1.3E-06	0.373	0.054
Towels	Electricity	Electricity, low voltage, at grid (US)	1775.47	28751.11	1.1E-03	554.834	110.018
Towels	Natural Gas	Natural gas, burned in industrial furnace low-NOx >100kW	887.62	16377.23	9.7E-05	28.517	4.118
2. Manufacturing	Stage Total		2710.93	45929.41	1.2E-03	595.047	116.435
3. Transportation							
Towels	Inbound - Ship	Transport, transoceanic freight ship	8.67	135.85	1.9E-05	1.873	0.167
Towels	Inbound - Truck	Transport, lorry 20-28t, fleet average	156.27	2622.13	1.7E-04	58.433	2.790

Towels	Outbound - Ship	Transport, transoceanic freight ship	8.67	135.85	1.9E-05	1.873	0.167
Towels	Outbound - Truck	Transport, lorry 20-28t, fleet average	156.27	2622.13	1.7E-04	58.433	2.790
liners	Inbound - Ship	Transport, transoceanic freight ship	0.72	11.36	1.6E-06	0.157	0.014
liners	Inbound - Truck	Transport, lorry 20-28t, fleet average	13.07	219.32	1.4E-05	4.887	0.233
liners	Outbound - Ship	Transport, transoceanic freight ship	0.72	11.36	1.6E-06	0.157	0.014
liners	Outbound - Truck	Transport, lorry 20-28t, fleet average	13.07	219.32	1.4E-05	4.887	0.233
Dispensor	Inbound - Ship	Transport, transoceanic freight ship	0.02	0.36	5.0E-08	0.005	0.000
Dispensor	Inbound - Truck	Transport, lorry 20-28t, fleet average	0.41	6.88	4.5E-07	0.153	0.007
Dispensor	Outbound - Ship	Transport, transoceanic freight ship	0.02	0.36	5.0E-08	0.005	0.000
Dispensor	Outbound - Truck	Transport, lorry 20-28t, fleet average	0.41	6.88	4.5E-07	0.153	0.007
Waste Bin	Inbound - Ship	Transport, transoceanic freight ship	0.06	0.92	1.3E-07	0.013	0.001
Waste Bin	Inbound - Truck	Transport, lorry 20-28t, fleet average	1.05	17.68	1.2E-06	0.394	0.019
Waste Bin	Outbound - Ship	Transport, transoceanic freight ship	0.06	0.92	1.3E-07	0.013	0.001
Waste Bin	Outbound - Truck	Transport, lorry 20-28t, fleet average	1.05	17.68	1.2E-06	0.394	0.019
End of Life	Truck	Transport, lorry 20-28t, fleet average	0.39	6.55	4.3E-07	0.146	0.007
3. Transportation	Stage Total		360.93	6035.52	4.2E-04	131.975	6.473
4. Use							
		Placeholder	0.00	0.00	0.0E+00	0.000	0.000
4. Use	Stage Total		0.00	0.00	0.0E+00	0.000	0.000
5. End of Life							
Towels	Landfilled	Disposal, paper, 11.2% water, to sanitary landfill	841.98	371.60	2.6E-05	8.959	1.933
Towels	Incinerated	Paper incineration: with energy recovery	-100.38	-1717.10	1.7E-05	-20.947	-4.873
Towels	Landfilled	Disposal, paper, 11.2% water, to sanitary landfill	0.00	0.00	0.0E+00	0.000	0.000
Towels	Incinerated	Paper incineration: with energy recovery	0.00	0.00	0.0E+00	0.000	0.000
Liners	Landfilled	Disposal, polyethylene, to sanitary landfill	7.75	22.22	1.1E-06	0.444	0.034
Liners	Incinerated	LDPE incineration: with energy recovery	24.23	-456.69	-7.6E-06	-6.789	-1.309
Dispensor	Landfilled	Disposal, plastics, mixture, to sanitary landfill	0.19	0.68	3.5E-08	0.014	0.001
Dispensor	Incinerated	Plastic mixture incineration: with energy recovery	0.53	-11.30	-1.4E-07	-0.167	-0.032
Waste Bin	Landfilled	Disposal, steel, to inert material landfill	0.04	0.98	4.6E-08	0.014	0.001
Waste Bin	Incinerated	Disposal, steel, 0% water, to municipal incineration	0.02	0.42	3.3E-07	0.009	0.001
Cardboard Packaging	Recycled	Cardboard - recycling: net impacts	-0.86	-4.09	-1.2E-05	-17.209	-1.594
Cardboard Packaging	Landfilled	Disposal, packaging cardboard, to sanitary landfill	27.61	9.09	6.7E-07	0.179	0.044

Cardboard Packaging	Incinerated	Cardboard - incineration: net impacts	-3.03	-51.36	7.3E-08	-0.753	-0.143
Batteries	Landfilled	Disposal, municipal solid waste, to sanitary landfill	0.17	2.79	1.5E-07	0.051	0.004
Batteries	Incinerated	Disposal, municipal solid waste, 22.9% water, to municipal incineration	0.45	3.37	1.2E-07	0.041	0.009
5. End of Life	Stage Total		798.70	-1829.39	2.6E-05	-36.154	-5.925
	Grand Total		5238	77038	3.4E-03	2371	213.6

6.3 Assumptions and Sources of Information

Assumptions

System	Information or Data	Value or Assumption	Source
All	Optics assembly mass	0.15 kg	(Gagnon and Panaretos 2009)
	Number of uses annually per system	26,000 (500 per week)	Consistent with (Madsen 2007)
	Packaging Recycling Rates	Based on post-consumer averages for the US.	(U.S. EPA 2007)
	Incineration Rates	For all materials not recycled, it has been assumed that 20% of these materials are sent to incineration rather than landfilled.	(UNEP 2007)
	Shipping from production facilities to point-of use (all components)	750 km by truck, 750 km by ship	Consistent with (Environmental Resources Management 2001)
	Inbound shipping distances for all production components	750 km by truck, 750 km by ship	Consistent with (Environmental Resources Management 2001)
	Replacement of components for dryers and towel dispensors	1% of all parts over the lifetime of the unit.	Based on information from Excel Dryer, Inc. (Gagnon and Panaretos 2009)
	End-of-life transport distance and mode	200 km by heavy-duty diesel vehicle	Assumption
XLERATOR	Drying time	12 seconds	Upper bound value from (Aisenberg and Freedman)
	Total Mass	9.4 kg (ranges from 7.9kg to 10.6 kg, depending on cover type)	(Gagnon and Panaretos 2009)
	Wattage	1500 w	(Gagnon and Panaretos 2009)
	Shutdown time and wattage	An additional 1.5 s operating at an average 50% of full wattage.	(Gagnon and Panaretos 2009)
Conventional hand dryer	Drying time	35 seconds	In lower range from (Aisenberg and Freedman)
	Total Mass	6.4 kg	(Environmental Resources Management 2001)
	Wattage	2300 w	(Gagnon and Panaretos 2009) and (Environmental Resources Management 2001)
	Shutdown time and wattage	An additional 1.5 s operating at an average 50% of full wattage.	(Gagnon and Panaretos 2009)
	Inbound shipping distances for all production components	750 km by truck, 750 km by ship	Consistent with (Environmental Resources Management 2001)
Paper Towels	Size of towel	0.0733 m2	(Madsen 2007)
	Towel density	0.027 kg / m2	(Madsen 2007)
	Pulp to finished towel product ratio	1.0385	(Madsen 2007)
	Natural Gas used in towel manufacture	1600 MJ per 130 kg of product	(Madsen 2007)
	Electricity used in towel	964 MJ per 130 Kg of product	(Madsen 2007)

Paper Towels	manufacture		
	Change in towel manufacturing energy with recycled content	None	Consistent with (Madsen 2007)
	Number of towels per use	2 (with scenarios of 1 and 3)	Consistent with (Environmental Resources Management 2001); Madsen 2007 assume 1.5 towels; Gagnon and Panaretos suggest 2.5
	Waste bins used	1 for 10 year lifetime	Consistent with (Environmental Resources Management 2001)
	Waste bin weight and composition	6.2 kg, steel	Consistent with (Environmental Resources Management 2001)
	Waste liner bags used	5 per week	(Environmental Resources Management 2001)
	Battery usage	2 AA batteries, replaced each 6 months	Assumption
	Waste liner bag weight and composition	0.033 kg Polyethylene	(Environmental Resources Management 2001)
	Dispenser weight and composition	2.6, HDPE	(Environmental Resources Management 2001)
	Inbound shipping distances for all production components	750 km by truck, 750 km by ship	Consistent with (Environmental Resources Management 2001)

6.4 Allocation

Some processes in the life cycles of the products that have been studied involve interactions with other products or systems. This occurs especially during production (e.g., energy use and fuel use are aggregated at the plant level for many production lines) and during distribution (more than one product will likely be transported in the same truck). This type of situation makes it necessary to determine what share of the material, energy and emission flows can be allocated to the products in question.

For the delivery and distribution phase, impacts have been allocated assuming that the distribution impacts are proportional to the weight transported and the distance traveled, regardless of the products being co-transported.

For manufacturing processes, attempts have been made to isolate processes for these products to the extent necessary. On-site energy usage at the Excel Dryer production facility has been allocated evenly to all products being produced at the production plant on a per-item basis (all products are electric hand dryers).

A particularly difficult allocation problem arises in the case of the use of recycled materials in the paper towel system. While there is no clear consensus on how to allocate impacts of the original production of materials that have been recycled (Reap et al. 2008), numerous methods have been developed and applied in various cases(T. Ekvall and A.M. Tillman 1997). The problem is in deciding how much of the impacts that have occurred prior to the material entering the current system should be attributed to the current system. In addition, there is an analogous question of what portion of the impact of disposing of materials should be allocated to prior systems rather than the current one.

Figure 15 shows the course that the recycled paper pulp takes over its several uses. We can state the allocation question by asking what percentage of the impacts occurring at each of these stages should be assigned to the towels. Generally, it will be accepted that any impact from manufacturing or use of the towels should be assigned entirely to that system. Similarly, none of the impacts from manufacturing or using prior products would be assigned to the towels. The original production of the pulp, the recycling of the prior product into recycled pulp and the disposal processes are therefore the places where allocation may be applied.

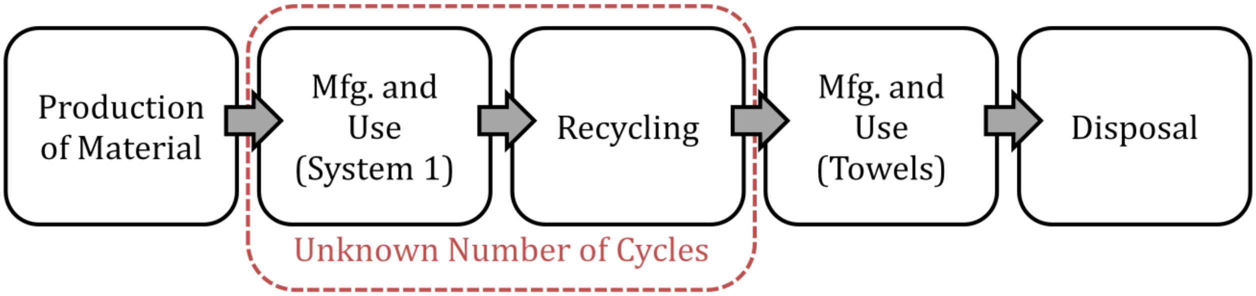

Figure 15: Depiction of the movement of recycled materials through prior systems and the present system. The stages circled in red may have occurred an unknown number of times.

In the present study, impacts from the original production of the pulp have not been allocated to the towel system (0% allocation). . It is therefore assumed that these impacts are attributed entirely to the prior systems that made use of the virgin content. Production of the recycled pulp from collecting, sorting and processing the prior paper products have been allocated entirely to the system. It is further assumed that 100% of the impact or benefit of disposing of the paper towels are allocated to the paper towel system. This is the “cut-off” approach presented in Ekvall and Tillman (1997).

To examine the importance of this methodological choice, two additional options are considered, as discussed in section 2.7 and shown in **Figure 10**. These include the allocation of only 50% of the impacts for recycled pulp production and end-of-life to the towel system (a “best case” for the towels), and the allocation of 50% of the original pulp production to the paper towels (a ‘worst case”).

For materials that are put to a beneficial use at the end of their life (e.g. recycling or waste-to-energy), a system expansion approach has been used to account for the benefits at end-of-life and 100% of those benefits, in addition to all end-of-life impacts are assigned to the product system. For example, when cardboard is recycled, the impacts of transporting the cardboard to a recycling facility and the energy used in recycling are accounted for and a credit is then given to the system equal to the impacts of producing virgin cardboard. Similarly, for energy recovery a credit is given for production of electricity or heat by other means.

6.5 Summary of Quality and Consistency

The following table summarizes the consistency of the methodology and data sources used across the three systems examined.

Category	XLERATOR Hand Dryer		Conventional hand dryer		Paper Towels		Consistency
	Description	Quality	Description	Quality	Description	Quality	
System Data Source	Manufacturer, with some information from literature to ensure consistency	Consistent with goal and scope	Prior LCA studies, with verification from manufacturer	Consistent with goal and scope	Prior LCA studies based on manufacturer data	Consistent with goal and scope	Very good
LCI Data Source	Entirely from ecoinvent 2.01	Consistent with goal and scope	Entirely from ecoinvent 2.01	Consistent with goal and scope	From ecoinvent 2.01, excepting 2 processes (IDEMAT)	Consistent with goal and scope	Very good
Data Accuracy	Good	Consistent with goal and scope	Good	Consistent with goal and scope	Good, with the exception of recycled pulp production	Acceptable, but might be improved	Good
Data Age	LCI data very current, system characteristics current	Consistent with goal and scope	LCI data very current, system characteristic within 10 years	Consistent with goal and scope	LCI data very current, system characteristic within 5 years	Consistent with goal and scope	Very good
Technology Coverage	Specific to exact product	Consistent with goal and scope	Representative of product category	Consistent with goal and scope	Representative of product category	Consistent with goal and scope	Very good
Temporal Coverage	Representative of present situation	Consistent with goal and scope	Representative of present situation	Consistent with goal and scope	Representative of present situation	Consistent with goal and scope	Very good
Geographic Coverage	US, with data point substituted from region with similar technology (Europe) where needed to maximize accuracy and completeness	Acceptable, but might be improved	US, with data point substituted from region with similar technology (Europe) where needed to maximize accuracy and completeness	Acceptable, but might be improved	US, with data point substituted from region with similar technology (Europe) where needed to maximize accuracy and completeness	Acceptable, but might be improved	Very good

6.6 Uncertainty Assessment

To test the certainty of the results, an uncertainty assessment has been made. The approach taken is to determine the uncertainty distributions of each system and of the ratios of the systems based on the uncertainty of input parameters. The uncertainty in ratios is a critical metric to assess because it accounts for the interdependence of some aspects of the uncertainty among systems.

The analysis has been made following the method of Hong *et al.* (2009). In brief, the uncertainty of each system is considered to be comprised of uncertainty in the quantities of: 1) the reference flows; and 2) the emission factors (or factor of other types of impacts) that are used to determine the life cycle inventory based on the reference flows. The uncertainties in these two types of input parameters can be used to determine the overall level of uncertainty based on the equation:

$$(\ln GSD_y)^2 = S_1^2(\ln GSD_1)^2 + S_2^2(\ln GSD_2)^2 + \ldots + S_n^2(\ln GSD_n)^2$$

GSD_y is the geometric standard deviation of the result. GSD_1 is the geometric standard deviation of the first input (e.g., a reference flow or emission factor) and S_1 is the sensitivity of the result to that factor. The sensitivities are defined as the percent response in the output to modification to the input and are identical to the percent contributions of the process in question to the overall result.

The GSDs of the reference flows have been determined based on the pedigree matrix approach of Frischknect *et al.*, 2005. The guidance of Frishknect *et al*. 2007 has been used to estimate the pedigree components. Of the 54 processes contributing to the systems, uncertainty in the emission factors have been determined based on Monte Carlo modeling in SimaPro software based on the Ecoinvent 2.01 database. For the remaining 17 processes where the data has not been taken directly from Ecoinvent (e.g., has been modified or from another data source), a GSD has been set as an upper bound of those that were measured with Monte Carlo simulation (for GWP_{100}, a GSD of 1.75 was used). As is shown in Table 10 below, none of these processes for which an uncertainty was not directly modeled shows a substantial contribution to the uncertainty of the comparisons (less than 3% for each).

Table 8 below shows the key uncertainty parameters for climate change impacts resulting from the analysis for each of the four systems that have been studied. The distributions of the probability for the climate change impacts for these four systems are shown in Figure 16.

Table 8: Uncertainty Parameters for the climate change impacts for the four systems studied

GWP (Kg CO_2) Eq.)	XLERATOR Hand Dryer	Conventional Hand Dryer	Paper Towels	100% Recycled
GSD^2	1.73	1.85	1.30	1.35
Median (GWP)	1422	4530	5238	4521
95% lower bound	823	2450	4028	3343
95% upper bound	2456	8375	6811	6114

Figure 16: Probability distributions of the climate change impacts of the four systems studied

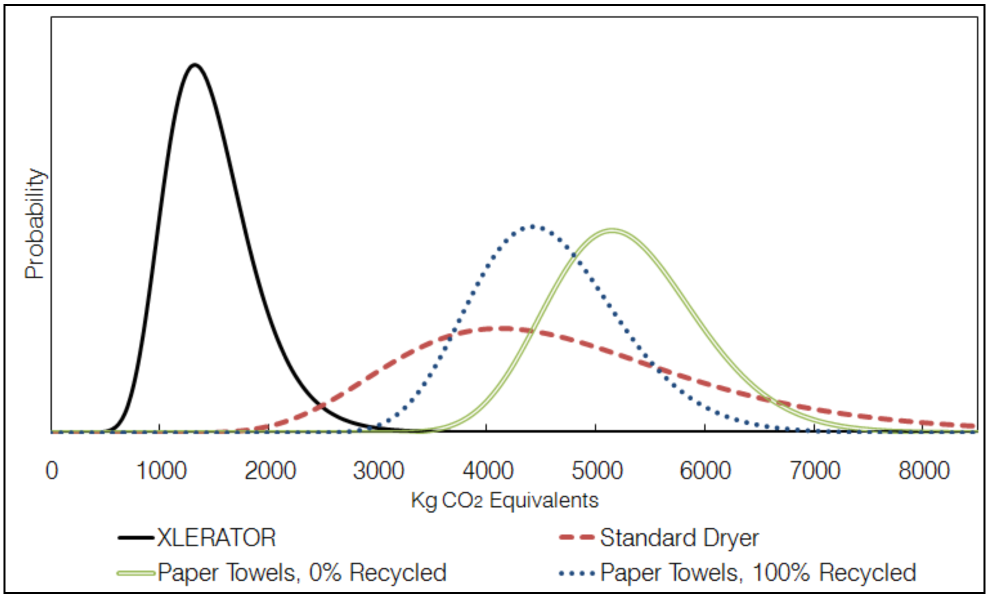

Table 8and Figure 16 show that the difference between the XLERATOR and the paper towels is statistically significant, with the upper bound of the range containing 95% of the results for the XLERATOR remaining below the lower bound of the 95% range for each of the towel systems. While the median value of the XLERATOR is substantially lower than the median for the conventional hand dryer, Table 1 shows that their 95% ranges overlap very slightly.

Drawing comparisons based on the results in Table 1 and Figure 1 overestimate the uncertainty in comparisons among the systems because some aspects of the uncertainty in the systems is uncertainty in the same information and while it contributes to the certainty of results of each system, it does not contribute as substantially to the uncertainty of the comparison among systems.

In addition to determining the uncertainty of the result for each system, Hong *et al.* (2009) also present a method for assessing the uncertainty of the ratios of the results for two systems. This allows a statement of confidence in the conclusion that one system has a greater impact than another. This is performed using the following formula:

$$(\ln GSD_{\frac{A}{B}})^2 = \sum_i^l S_{A_i}^2 (\ln GSD_i)^2 + \sum_{j=l+1}^m S_{B_j}^2 (\ln GSD_j)^2 + \sum_{k=m+1}^n (S_{A_k} - S_{B_k})^2 (\ln GSD_k)^2$$

S_{Ai} and S_{Bj} are the deviations of the independent processes or scenarios A and B, respectively. S_{Ak} and S_{Bk} are the sensitivities of common parameters for scenarios A and B, respectively. GSD_i and GSD_j are the geometric standard deviations of the independent processes or scenarios A and B. respectively GSD_k is the geometric standard deviation of common parameters for both scenarios.

The inputs and results of the assessment for global warming potential are shown below. Table X shows the sensitivity of each process, the inputs and result for determining the GSD of the reference flow, the GSD used for the emission/impact factor, and the percent contribution of each process to the total uncertainty of each of the four systems.

Table 9 shows the results of the analysis for the comparisons of systems.

Table 9: Results of uncertainty assessment, showing the probability that each system has a lesser global warming potential than the other systems

Comparison of (A / B):	Ratio	GSD	95% lower bound of ratio	95% upper bound of ratio	Probability A<B	Probability B<A
XLERATOR / Conventional hand dryer	0.31	1.06	0.28	0.35	0.9999	3.5E-07
XLERATOR / Paper Towels	0.27	1.19	0.19	0.39	0.9999	3.5E-07
XLERATOR / Towels 100% Recycled	0.31	1.18	0.23	0.44	0.9999	3.5E-07
Conventional hand dryer / Paper Towels	0.86	1.23	0.57	1.31	0.76	0.24
Conventional hand dryer / Towels 100% Recycled	1.00	1.22	0.68	1.48	0.50	0.50
Paper Towels / 100% Recycled	1.16	1.05	1.06	1.27	6.9E-04	0.999

The results are shown graphically in Figure 17: Results of uncertainty assessment, showing ranges of uncertainty for the ratios of the total global warming potential of the four systems compared

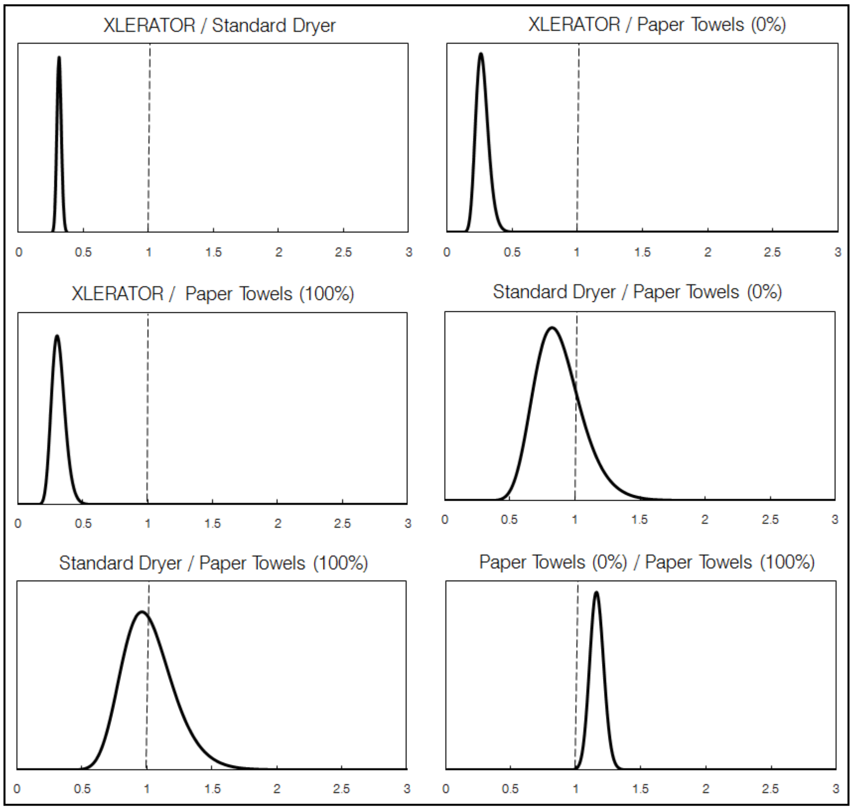

Figure 17: Results of uncertainty assessment, showing ranges of uncertainty for the ratios of the total global warming potential of the four systems compared

The result indicating a benefit for the XLERATOR system in comparison to the other three systems is quite robust, with less than a one in a million chance that the opposite case is true.

In addition, the recycled content paper towels show a significant advantage over the standard towels. However, it should be pointed out that the uncertainty analysis does not take into account the methodological issues relating to allocating for recycled content and that the data used does not include impacts for the processing of the recycled paper. For the comparison of the conventional hand dryer to either paper towel system, the result is clearly within the range of uncertainty of the study.

Table 10: Inputs to the uncertainty analysis and percent contributions to the results by process (A = XLERATOR hand dryer, B = Conventional hand dryer, C = Standard towels, D = Towels with 100% recycled content)

Process	Sensitivity A	Sensitivity B	Sensitivity C	Sensitivity D	Reliability Factor	Completeness Factor	Temporal Correlation	Geographical Correlation	Technological Correlation	Sample Size Factor	Base Uncertainty Factor	GSD Reference Flow	GSD GWP Factor	Percent contribution to comparison:					
														A/B	A/C	A/D	B/C	B/D	C/D
Natural gas, burned in industrial furnace low-NOx >100kW	0.82%	0.26%	17.17%	19.89%	2	3	3	3	1	5	1.05	1.05	1.14	0.01%	0.44%	0.68%	0.33%	0.51%	2.18%
Electricity, low voltage, at grid (US)	83.9%	95.2%	34.6%	40.1%	2	3	3	1	1	5	1.05	1.05	1.90	75.41%	82.41%	75.50%	89.19%	84.42%	22.80%
Transport, lorry 20-28t, fleet average	0.32%	0.07%	6.53%	7.56%	2	3	3	3	1	5	2	1.70	1.84	0.04%	2.11%	3.29%	1.58%	2.42%	33.36%
Transport, transoceanic freight ship	0.01%	0.00%	0.36%	0.42%	2	3	3	3	1	5	2	1.70	1.15	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%
Sulphate pulp, average, at regional storage	0.00%	0.00%	16.24%	0.00%	2	3	3	3	1	5	1.05	1.05	1.30	0.00%	1.52%	0.00%	1.09%	0.00%	22.34%
Disposal, paper, 11.2% water, to sanitary landfill	0.00%	0.00%	16.07%	18.62%	2	3	3	3	1	5	1.05	1.05	1.90	0.00%	8.55%	13.22%	6.14%	9.39%	4.92%
Paper incineration: with energy recovery	0.00%	0.00%	-1.92%	-2.22%	2	3	3	3	3	5	1.05	1.09	3.06	0.00%	0.37%	0.58%	0.27%	0.41%	0.21%
LDPE, extruded to film	0.01%	0.00%	4.30%	4.98%	2	3	3	3	1	5	1.05	1.05	3.06	0.00%	1.85%	2.87%	1.34%	2.05%	0.81%
Disposal, polyethylene, to sanitary landfill	0.00%	0.00%	0.15%	0.17%	2	3	3	3	1	5	1.05	1.05	2.55	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Battery D	0.00%	0.00%	0.36%	0.42%	2	3	3	3	3	5	1.05	1.09	3.06	0.00%	0.01%	0.02%	0.01%	0.01%	0.01%
Corrugated board, fresh fibre, single wall, at plant	0.01%	0.01%	0.95%	1.10%	2	3	3	3	1	5	1.05	1.05	1.17	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
LDPE incineration: with energy recovery	0.00%	0.00%	0.46%	0.54%	2	3	3	3	3	5	1.05	1.09	3.06	0.00%	0.02%	0.03%	0.02%	0.02%	0.01%
Cardboard - recycling: net impacts	0.00%	0.00%	-0.02%	-0.02%	2	3	3	3	3	5	1.05	1.09	3.06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Steel, converter, chromium steel 18/8, at plant	1.07%	0.00%	0.63%	0.73%	2	3	3	3	1	5	1.05	1.05	1.17	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, packaging cardboard, to sanitary landfill	0.00%	0.01%	0.53%	0.61%	2	3	3	3	1	5	1.05	1.05	1.82	0.00%	0.01%	0.01%	0.01%	0.01%	0.00%
Disposal, steel, to inert material landfill	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.61	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Zinc, primary, at regional storage	0.51%	0.04%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.32	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, steel, 0% water, to municipal incineration	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Cardboard, with printing, from primary materials	0.00%	0.00%	0.11%	0.12%	2	3	3	3	1	5	1.05	1.05	3.06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Glass fibre reinforced plastic, polyamide, injection moulding, at plant	0.75%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.25	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, plastics, mixture, to sanitary landfill	0.01%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	3.06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Plastic mixture, with extrusion	0.10%	0.00%	0.19%	0.22%	2	3	3	3	3	5	1.05	1.09	3.06	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Steel, with formation to product	0.00%	0.15%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	3.06	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%
Cardboard - incineration: net impacts	0.00%	0.00%	-0.06%	-0.07%	2	3	3	3	1	5	1.05	1.05	3.06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, aluminium, 0% water, to sanitary landfill	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.38	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sealing tape, aluminum/PE, 50 mm wide, at plant	0.02%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.27	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, municipal solid waste, to sanitary landfill	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	2.03	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Aluminum, with formation, from primary materials	0.00%	0.29%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	3.06	0.09%	0.00%	0.00%	0.01%	0.01%	0.00%
Aluminum, with formation, produced from secondary	0.00%	0.09%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	3.06	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%
Plastic mixture incineration: with energy recovery	0.02%	0.00%	0.01%	0.01%	2	3	3	3	1	5	1.05	1.05	3.06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Copper, primary, at refinery	0.11%	0.03%	0.02%	0.02%	2	3	3	3	1	5	1.05	1.05	1.26	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Acrylonitrile-butadiene-styrene copolymer, ABS,	0.13%	0.01%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.01	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Process	Sensitivity A	Sensitivity B	Sensitivity C	Sensitivity D	Reliability Factor	Completeness Factor	Temporal Correlation	Geographical Correlation	Technological Correlation	Sample Size Factor	Base Uncertainty Factor	GSD Reference Flow	GSD GWP Factor	Percent contribution to comparison:					
														A/B	A/C	A/D	B/C	B/D	C/D
at plant																			
Electronic component, active, unspecified, at plant	12.19%	3.83%	3.31%	3.83%	2	3	3	3	1	5	1.05	1.05	1.91	24.34%	2.70%	2.76%	0.01%	0.00%	0.21%
Disposal, steel, 0% water, to inert material landfill	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.61	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, zinc in car shredder residue, 0% water, to municipal incineration	0.01%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.25	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, aluminium, 0% water, to municipal incineration	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.38	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, municipal solid waste, 22.9% water, to municipal incineration	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.38	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Electroplating Chrome I	0.01%	0.00%	0.00%	0.00%	2	1	3	3	1	5	1.05	1.05	3.06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, wood untreated, to municipal incineration, net benefits	0.00%	0.00%	0.00%	0.00%	2	3	3	3	3	5	1.05	1.09	3.06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
disposal, hazardous waste, 25% water, to hazardous waste incineration	0.00%	0.00%	0.01%	0.01%	2	3	3	3	1	5	1.05	1.05	1.42	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
disposal, hazardous waste, 0% water, to underground deposit	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	2.34	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Corrugated board, recycled fibre, single wall, at plant	0.01%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.17	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nylon 6, at plant	0.00%	0.02%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Ceramic tiles, at regional storage	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.24	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
LLDPE - incineration: net impacts	0.01%	0.00%	0.00%	0.00%	2	3	3	3	3	5	1.05	1.09	3.06	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Polyethylene, LDPE, granulate, at plant	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, copper, to municipal incineration	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.37	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Disposal, wood, untreated, to sanitary landfill	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	2.82	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Epoxy resin, liquid, at plant	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.00	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Chromium, at regional storage	0.01%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.22	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nickel, 99.5%, at plant	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.16	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sawn timber, softwood, planed, kiln dried, at plant	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.73	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
electricity, hard coal, at power plant	0.00%	0.00%	0.00%	0.00%	2	3	3	3	1	5	1.05	1.05	1.15	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Recycled Pulp Production and EOL Paper Collection	0.00%	0.00%	0.00%	2.96%	2	3	3	3	3	5	1.05	1.09	3.06	0.00%	0.00%	1.02%	0.00%	0.72%	13.02%